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Genesis and morphology of two soils with fragipans in Massachusetts :: the Paxton and Mills series.

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GENESIS AND MORPHOLOGY OF TWO

SOILS WITH FRAGIPANS IN MASSACHUSETTS

THE PAXTON AND MILLIS SERIES

by

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A THESIS

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INTRODUCTION

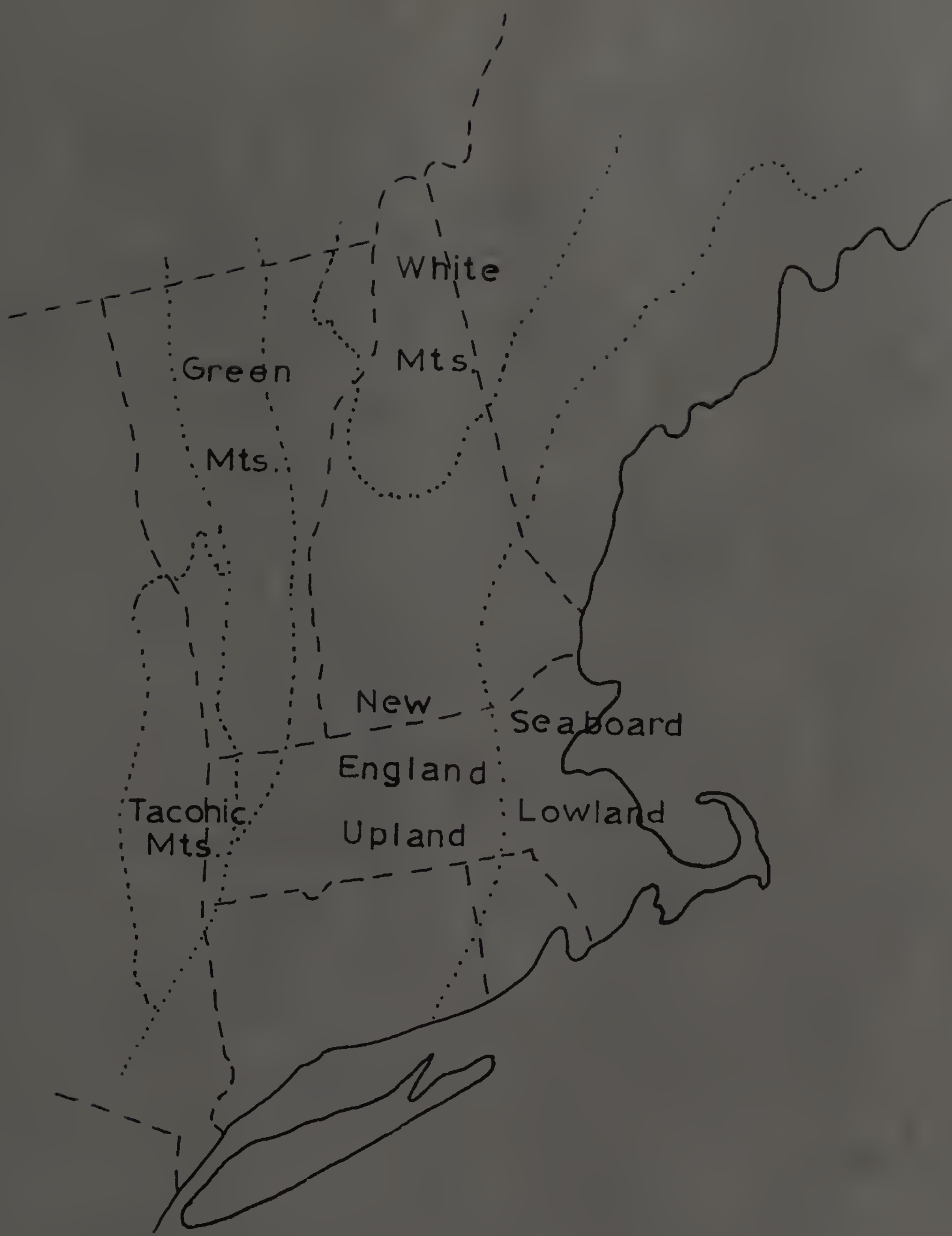
The Paxton and Millis soils have been selected for a detailed study of fragipans in Massachusetts. A basic study of the genesis and morphology of soils with fragipans is essential to better understand their effect upon land and land use. Such a study should also allow correlation between fragipan soils in Massachusetts and other parts of the United States.

Throughout this study Paxton and Millis soils will be referred to as Paxton and Millis.

PHYSIOGRAPHY OF MASSACHUSETTS

Fenneman (1938 p. 345) divides New England into five distinct provinces (Fig. 1). In Massachusetts the New England Upland and the Seaboard Lowland are most extensive. The New England Upland is an upraised peneplain with occasional monadnocks and dissected by narrow valleys. Altitudes range from 1000 to 2000 feet; steep slopes are common. The Connecticut Valley occurs within the New England Upland and is moderately level or rolling.

The Seaboard Lowland is a coastal strip that is lower and smoother than the adjacent uplands. Several very flat areas such as the Boston Basin and the Naragansett Basin, occur within the Seaboard Lowland.



Physiographic provinces of New England

Fig. 1

Paxton and Hollis occur in the New England Uplands
and the Seaboard Lowland of Massachusetts

GEOLOGY OF MASSACHUSETTS

The dominant rocks in Massachusetts are metamorphosed Paleozoic sedimentary and volcanic rocks, mostly schist, geneiss and phyllite; exceptions include Triassic Jurassic rocks of the Connecticut Valley in central Massachusetts, the Pennsylvanian rocks of the Narragansett basin in southeastern Massachusetts and the late Paleozoic rocks of the Boston basin in eastern Massachusetts. These areas of sedimentary rocks generally produce broad lowlands, while the metamorphosed rocks vary greatly in topographic expression from lowlands to residual mountains (Schafer and Hartshorn, 1965, p. 113).

Continental glaciers are believed to have covered New England several times. Glacial erosion has had little effect on areas of high bedrock relief, and the stream-carved landscape of pre-Pleistocene time is fundamentally the same as today. Many areas of lower relief, such as much of eastern Massachusetts, have disrupted drainage due to obstruction of bedrock valleys by glacial deposits (Hansen, 1953).

Tills in Massachusetts are texturally and lithologically variable. Types of tills are determined by bedrock lithology. Clay-size material is usually less than 10% but may be as much as 25% in some drumlin tills. Clay minerals make up only a small percentage of the clay-size material of tills (Schafer and Hartshorn, 1965).

The thickness of drift is variable and is dependent on so many factors that local thickness values have no great significance. Schafer and Hartshorn (1965, p. 115), however, estimate that the average depth of drift for New England is less than 10 meters. Flint (1971, p. 150) lists 3-5 meters of drift as an average depth for east central Massachusetts.

The depth of till is perhaps greatest in buried valleys and on drumlins. Some drumlins in New England consist of till with a rock core (Flint 1971, p. 100).

Of particular interest is the two till problem in New England. Two texturally and structurally distinct tills believed to be different in age occur in New England. These tills have been described in Massachusetts, New Hampshire, and Connecticut by many authors; some of the more recent include: Schafer and Hartshorn (1965), Pessl (1966) and Pessl and Schafer (1968).

The lower till is more compact, has a higher average content of silt and clay (e.g., 44% sand, 43% silt, 5% clay) (Pessl, 1966), and coarse fragments are commonly less than 20%. It is oxidized to depths of about 4-9 meters. The oxidized material is commonly olive brown (2.5Y 5/4), is fissile or platy, and is usually vertically jointed.

The upper till, part of the Wisconsin drift sheet, is generally less compact, sandier (e.g., averaging 62% sand, 23% silt, and 2% clay) (Pessl, 1966) and with coarse fragments exceeding 20%. It is generally unoxidized, e.g., light olive gray (5Y 6/2). Textural layering is common, and generally sub-parallel to the topographic surface, and is most often expressed as lighter sandier lenses interbedded with darker siltier lens. Fissility or platyness is uncommon but does occur in the siltier, more compact phases of the upper till. Nowhere has the younger till been reported as the main constituent of drumlins. The younger till may occur as a ring around the lower part of some drumlins and rarely as a capping on some drumlins.

When both tills are present, upper till has always been found to occur on top of lower till. Therefore, the tills are commonly referred to as upper and lower tills (Figs. 2 and 3). Upper and lower are less objection-

Fig. 2 Lower till. Platy structure is pronounced because of exposure to surface.

Fig. 3 Upper till. Distorted bedding structures are common to many upper tills.

able terms for the tills because they do not reflect an age interpretation which may not be acceptable to all geologists. In general most geologists feel that the two tills are lodgement tills laid down by separate ice sheets. However, there are many hypotheses involving relative ages and modes of deposition of upper and lower tills.

GENERAL DESCRIPTION OF PAXTON AND MILLIS SOILS

Parent materials of Paxton and Millis soils is till or till-like material. Paxton is developed from lower glacial till and Millis is developed from upper till. Paxton soils often occur on drumlins. Millis is found most frequently on bedrock controlled ground moraine. However both Paxton and Millis may be found in many situations.

The Paxton and Millis soils have wide occurence east of the Connecticut Valley in Massachusetts (Fig. 4). A small area west of the valley also contains Paxton soils. Soils developed in the valley are usually too red to be classified as Paxton or Millis due to the reddish Triassic Jurassic parent materials found in the valley. Paxton and Millis soils are not found in the western part of the state because soils of this area have frigid temperature regimes or parent materials that are not characteristic of Paxton or Millis soils. In general, Paxton soils are more common in the New England Uplands and Millis soils are more common in the Seaboard Lowland (John Mott, Soil Conservation Service, Amherst, Massachusetts, personal communication, 1976).

Hill and Gonick (1963), estimate that there are 143,354 acres of Paxton soils in Massachusetts. Approximately 20% is cropland, 10% is pasture, 60% is woodland and the remaining 10% is idle or urban. The approximate acreage of the Millis soils is not known; however, the land use of Millis soils is similar to the Paxton soils.

Paxton and Millis series are well drained upland soils and are classified as Typic Fragiochrepts. The Paxton series is a member of a coarse loamy mixed mesic family and the Millis series is a member of a coarse loamy over sandy skeletal mixed misic family. Both series have umbric

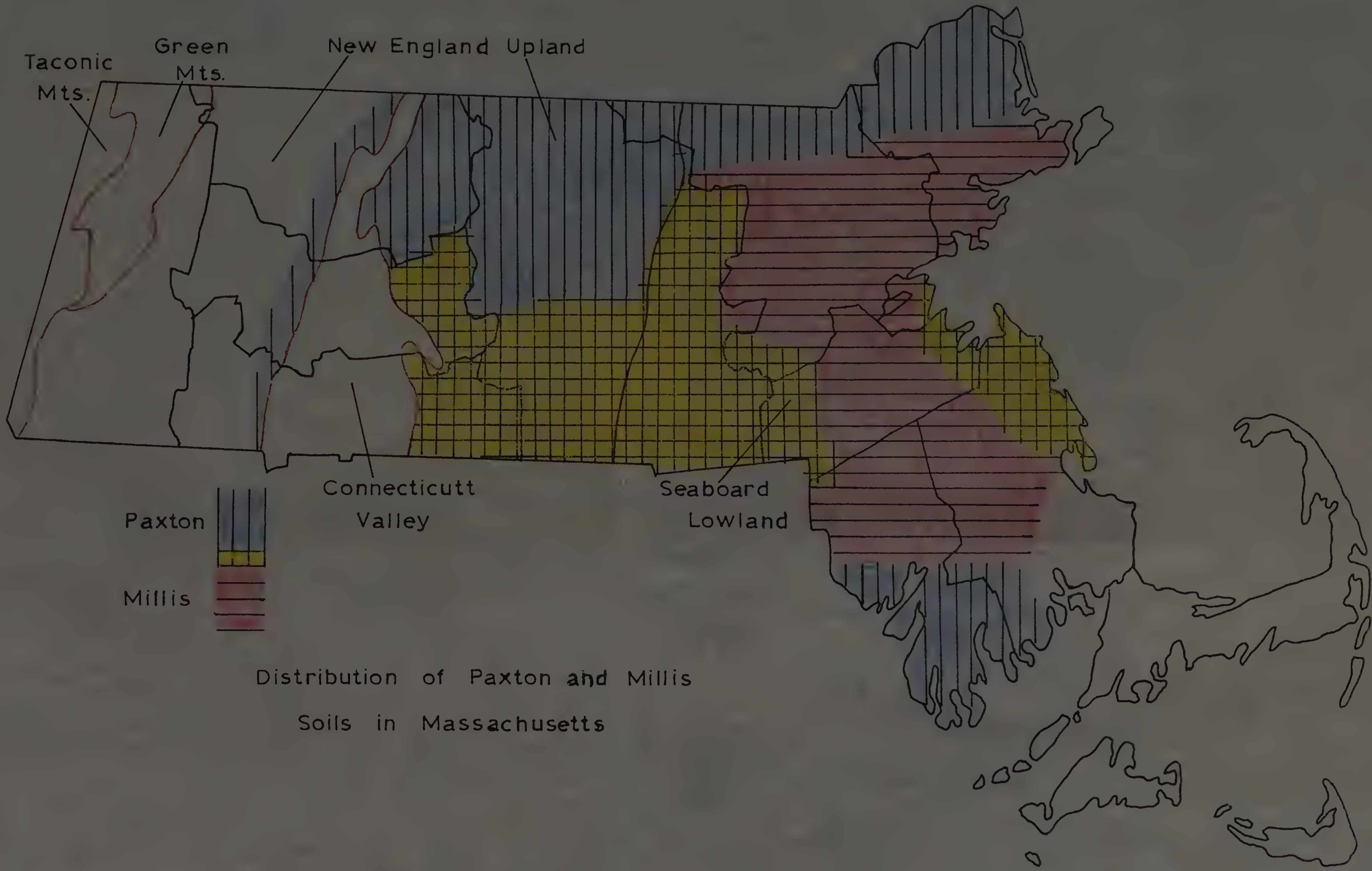


Fig. 4

Paxton soils are common in the New England Upland. Millis soils are common in the Seaboard Lowland.

epipedons and cambic subsurface horizons. Albic subsurface horizons are almost always absent, perhaps due to anti-eluviation (Lyford, 1963), man's disturbance (Hill and Gonick, 1963), or insufficient soil development (Flock, 1960). The structure of the A horizon is usually crumb and the B horizon is massive. Structure of the B horizons has been attributed to fungal hyphae enmeshing soil particles (Lyford, 1966). Hartshorn, (1965) and Colby and others, (1953) have stressed the importance of a windblown component in the A and B horizons of Massachusetts soils. The windblown material is more evident in the Millis series than in the Paxton although both soils may have distinct windblown mantles in places. In general material in the A and B horizons are thought to be a mixture of windblown material and frost stirred parent material (i.e., congeliturbate).

Established series descriptions of the Paxton and Millis series are given in the appendix including their range of characteristics.

One of the most striking features of the Paxton and Millis soils is a hardpan or fragipan at depths of 15 to 36 inches. Fragipans are given an important position at the Great Group level in the four orders they occur in: Inceptisols, Ultisols, Alfisols and Spodosols. Fragipans restrict root growth of plants and cause limitations on urban development. At present there is a controversy over the genesis and morphology of fragipans in Massachusetts.

LITERATURE REVIEW

Definition of Fragipans

Grossman and Carlisle (1969), Olson (1960) and Winters and Simonson (1951), have presented comprehensive reviews of soils with fragipans.

Soil Survey Staff (1970), gives the following definition of fragipans:

> "A fragipan (modified from L. fragilis, brittle; and pan, meaning brittle pan) is a loamy or uncommonly a sandy horizon that may, but does not necessarily, underlie a cambic, spodic, argillic, or albic horizon. It is very low in organic matter, has a high bulk density relative to the horizons above, is seemingly cemented when dry, having hard or very hard consistence. When moist, a fragipan has moderate or weak brittleness (tendency for a ped or clod to rupture suddenly when pressure is applied rather than undergo slow deformation. A dry fragment slakes or fractures when placed in water, and has few or many bleached roughly vertical planes that are faces of coarse or very coarse polyhedrons or prisms."

Many other definitions for fragipans for specific areas studied are presented by Olson (1963), Grossman and others (1959), Carlisle (1954), Nikiforoff (1955) and Smith and Browning (1946).

At present there is considerable confusion over the concept of fragipans. The problem is in the lack of a precise definition. Some fragipans are hard and brittle when dry but soften when moist (Yassoglou and Whiteside (1960). Grossman and Carlisle (1969) give the principal defining properties as high bulk density, hardness and brittleness when dry, and brittleness when moist.

Hardness of fragipans is probably due to close packing of particles (Horn and Rutledge 1965, Yassoglou and Whiteside 1960). Bonding agents such as silica, aluminum and iron have been studied, but evidence so far has shown silicate clay to be the principal bonding agent (Grossman and Carlisle, 1969; Hutcheson and Bailey, 1964). Duripans grade into fragipans of humid climates where strength of cementation by silica and possibly accessory cements such as iron oxide, decrease until the dry pan slakes in water (Soil Survey Staff, 1970). Although duripans occur mostly in Mediterrean climates, it seems probable that some confusion in definition may result from different degrees of cementation by different cementing agents. Some fragipans take longer to slake in water than others, perhaps due to degree of cementation.

Consistence is a principal defining property of fragipans. The test for consistence is variable because of estimations involving water content of a ped and difference in skill of persons performing the test in the field. Attempts to show differences in consistence by mechanical methods have had some success (Grossman and Cline, 1957; Yassoglou and Whiteside, 1960; Horn and Rutledge, 1965).

Near-vertical cracks forming prisms, when viewed in plan, have been used as a defining property by some authors. However, vertical cracks are not present in some soils containing fragipans (Lyford, 1973).

The vagueness of the definition for fragipans creates problems in separating till or till-like colluvium of high bulk density from fragipans.

Since fragipans are viewed as genetic horizons (Soil Survey Staff 1970), a definition requiring evidence of movement of fines or rearrangement of particles within the fragipan matrix would separate till or till-like materials from fragipan horizons.

Geographic Occurrence of Fragipans

Fragipans are common throughout the eastern United States and many foreign countries, e.g., Canada, Africa, New Zealand, Greece, Scotland, Italy, Norway, and Sweden (Lyford and Troedsson, 1973, DeKimpe, 1972, Yassoglou and Whiteside, 1960).

Grossman and Carlisle suggest the following relationship in the broad-scale occurrence of fragipan soils:

> "(1) Fragipans are restricted to areas where the excess of precipitation over evapotranspiration is sufficient at some time of the year for movement of water down through the soil. (2) They occur in both warm and cold climates. (3) Fragipans seemingly are absent in soils of the extensive natural grasslands of the humid prairies and the Great Plains. (4) Fragipans occur in Spodosols, Inceptisols, Alfisols, and Ultisols."

Bartelli (Principal Soil Correlator, Soil Conservation Service, Washington, D.C., personal communication 1976) has observed three properties common to most fragipans - (1) a well graded particle size distribution, (2) a well defined wet and dry season with enough water to have downward movement through the soil, and (3) a discontinuity in moisture tension in the soil profile.

Fig. 5 shows areas within which fragipans are common in North America (Walter Lyford, Harvard School Forest, Petersham, Massachusetts, unpublished data, 1968).

In Massachusetts, soils with fragipans (as classified by the Soil Conservation Service) occur in soils developed from till parent materials and are absent from soils developed from other parent materials. Fragipans seem to occur more often in transported parent materials than in residuum, e.g., glacialacusirine sediments (Jha and Cline 1963), pitted outwash (Olson 1960), loess (Grossman and others 1959), eastern coastal plain (Nikiforoff 1955) and till (Yassoglou and Whiteside 1960; Carlisle 1954; DeKimpe and McKeague 1974; Lyford 1963). Fragipans do occur on residual parent materials outside of glacial areas (Rutledge and Horn 1965).

Soils with Fragipans

According to Grossman and Carlisle (1969), "all fragipans occur beneath an eluvial horizon unless the soil has been severely eroded. Some soils with fragipans are bisequal", (a sequum is comprised of an A and B horizon. A soil with two sequums is bisequal). In bisequal soils the fragipan may occur in the lower sequum. The suffix X is used to denote a fragipan horizon.

Features common to many fragipan soils include A′2 horizons, clay cutans, silt caps and sand beds, discontinuous pores, rough vertical planes that delineate large prisms or blocks of primary structure and horizontal platy peds of secondary structure.

Clay cutans refer to thin clay-rich coatings almost always assoc-

Areas where fragipans occur.

Fragipans are common throughout the eastern United States.

Fig. 5

iated with the horizontal dimensions of platy structural units. Miller and others (1971b), Lyford (1973), Yassoglou and Whiteside (1960), DeKimpe and McKeague (1974) and many other authors call attention to them.

Coarse fragments and pebbles are often found sheathed in silt and clay. Sheathing seems to be most common in soils formed from glacial till (Fitzpatrick, 1956; Brown and Tedrow, 1964; Romans, 1966; Yassoglou and Whiteside, 1960).

Silt caps and sand beds have been described by Carlisle (1954) and Lyford (1973). Geographical distribution of silt caps and sand beds is not well known. Silt caps are found on coarse fragments. The caps are usually 0.5 to 2 mm thick. Lyford (1973) states: "The silty capping is distinctly finer textured than the adjacent soil material and it adheres strongly to the coarse fragment. It tends to feather out in thickness at the edges of the coarse fragment on which it rests but in places can be traced horizontally into the surrounding finer soil material." Sand beds are found under coarse fragments and are about 1 mm thick. The sand is loose and appears to be clean and uncoated.

Discontinuous pores are common to almost all fragipans studied. Fragipans are often described as vesicular, implying that pores are not interconnected. Pores are often lined with silt or clay (Lyford, 1973; Carlisle, 1954; Yassoglou and Whiteside, 1960).

Primary structure of rough vertical planes forming prisms have been described by many authors. The prisms are well defined by light gray streaks. The light gray material is usually described as a silty infilling of vertical cracks. An iron enriched zone a few millimeters thick occurs adjacent to the light gray streaks (Gile, 1958; Miller and others, 1971a).

Secondary structure of fragipans is somewhat variable. Grossman and Carlisle (1969, p. 250), state: "Trends follow those for horizons other than fragipans: eluvial horizons usually are massive or platy; illuvial horizons usually are blocky." Fragipans in New York and New England are commonly platy (Lyford, 1963; Carlisle, 1954).

According to Grossman and Carlisle (1969) most fragipans are loamy and few are sandy. Clay amounts may vary; some fragipans exceed 35 percent clay but none have been reported with over 60 percent clay. Most fragipans contain less than 25 percent clay. It is probable that a high content of silt and fine sand is important in fragipan expression (Jha and Cline, 1963; Carlisle, 1954; Grossman and Cline, 1957; Knox, 1957).

The clay mineralogy of fragipans is similar to the clay mineralogy of horizons in similar positions in associated soils without fragipans.

Most fragipans studied microscopically have shown optically oriented clay to be present. The fabrics are usually described as plasmic and septic (Brewer, 1964; Grossman and Carlisle, 1969).

Genesis of Fragipans

Pedogenic Processes

Soil Survey Staff (1970) lists the following evidence for fragipans being genetic soil horizons:

1. The fragipan is roughly parallel to the soil surface.
2. The majority of the fragipans have their boundary about 40 to 80 cm below the surface if the soil is not eroded.
3. The fragipans occur in elluvium, in loess, in residuum from bedrock, in glacial till and in solifluction materials.

4. The fragipans are not known to occur in materials that are calcareous.
5. They always occur below an eluvial horizon and are therefore subject to the accumulation of substances from some horizon above.
6. The natural vegetation is exclusively forest.

Several hypotheses of the genesis for fragipans have been suggested. Yassoglou and Whiteside (1960) have postulated the following steps for the formation of fragipans they studied in northern Michigan: (1) Removal of part of the clay; preferentially the expanding clay. (2) Contraction following removal of the expanding clay and other soluble materials. (3) Rearrangement of the matrix substances. (4) Release of aluminum from decomposing mineral during soil development. Nikiforoff (1955), Carlisle (1954) and Miller and others (1971) have suggested that the contraction of the fragipan is due to desiccation rather than removal of clay and that compaction of the fragipan is inherited from the parent material.

Relationship of Fragipans To Events of the Pleistocene

In Massachusetts many of the features given as evidence for pedogenesis of fragipans may be related to glacial deposition.

Tills in Massachusetts have high densities e.g., 1.95 gm/cc (Lenill and Shea, 1960). Goldthwaite (1948) hypothesized that the densities of glacial tills in New Hampshire were related to water content during deposition rather than to the load of overlying ice. Engineers have known for years that a given particle size distribution will have a maximum compaction at a specific water content. Elson (1960) states:

> "Analysis of the energy involved in producing a compact till by crushing and grinding rock beneath the glacier shows that the heat produced is just adequate to melt enough ice to form about 8 percent water. This is approximately the median value required to obtain maximum density by artificial compaction in the till studied. It is suggested that rock debris crushed and abraded at the base of the ice by shearing action of the moving glacier generates the proper amount of water for maximum density by melting some of the basal ice; thus the system maintains thermodynamic equilibrium."

It seems probable that given the proper particle size distribution and the proper water content, high bulk densities will form regardless of illuvial material or rearrangement of fabric.

Fragipans in Massachusetts are usually platy. Platy structure is referred to as fissility in till deposits by geologists, and commonly reaches depths of 20 feet. This has been observed by the writer in a deep borrow pit in till at Thomaston Dam Connecticut. The cause of fissility in till is obscure. Virkhala (1952) suggests that fissility in glacial till could be caused by accreation of layers of drift. Joseph Hartshorn, Department of Geology, University of Massachusetts, personal communication, 1975) hypothesized that pressure parting or a pressure release upon removal of an ice load could cause fissility. Fitzpatrick (1956) made a study of fragipans in Spitzbergen, Norway, and related the nature of the horizons there primarily to ice action; he pointed out that ice lenses may have been the primary cause of platy structure. Ice may form horizontal wedges in the upper horizons of a soil profile thus forcing the soil apart along horizontal planes. Kubiena (1938, p. 193) proposed that platy structure may be developed as soil is desiccated from the top down. Drying from the top down produces a zone of accumulation of colloidal material at the evaporating surface. When an adjacent eluvial layer drys out, transportation is interrupted for a time, but will be resumed at a new surface. Boulton and Dent (1974) related glacial and pedological processes on recently exposed till in Iceland, along the frontal margin of the glacier Breidamerkurjokull. They state (p. 132) that "since the laminar structure (platiness) is completely developed in freshly-exposed till we conclude that in this instance it is of sub-glacial origin, presumably due to the pressure of the glacier."

Platy structure attributed to the action of ground water occurs in both glaciated and non-glaciated areas (Smith and Browning, 1946).

Sheathing of particles with silt or clay can be caused by ice action. Elson (1960) states that growing ice crystals within a glacier expel silt and clay-size particles and deposit them as coatings on pebbles and larger stones. This may explain the formation of some silt caps.

It is probable that most silt caps and sand beds are not caused by ice action. The silty coatings are almost always oriented in an upright (i.e., the coating is facing the topographic surface) position. This seems to imply illuviation. Boulton and Dent (1974), have observed that both a rapid downwashing and a deflation of silt take place immediately after deglaciation. The illuviation of silt is a probable cause of silt caps.

They state (p. 127): "The silt accumulates particularly on the upper surfaces of stones and initially on the surfaces of the compact platy peds." It is hard to view silt caps as a pedogenic process because they occur at considerable depths (e.g., 15 feet) in tills that have low hydraulic conductivities.

Near vertical cracks that form polygons when viewed in plan are thought to be formed by shrinkage following desiccation of the till (Flint, 1971 p. 159-160).

A′2 horizons are common to fragipan soils. In Massachusetts some A′2 horizons may be confused with a thin layer of upper till occurring on top of lower till. On drumlins, upper till overlies lower till either as a collar around the drumlin flanks or as a continuous thin mantle covering the entire drumlin (Pessl and Schafer 1968). Sand lens have also been observed in both upper and lower tills at considerable depths.

It is evident that till may be confused with pedogenic fragipans. Many of the features common in till may be confused with pedogenic features of fragipans. Many of the features common in fragipans and glacial till may have more than one genesis.

METHODS OF STUDY

General Procedure

Both the Paxton and Millis study sites are located in borrow pits. A portion of the faces of the pits were cut back approximately 3 feet and cleaned for observation and sampling. A 3 pound bag sample was taken of each horizon for physical and chemical analysis. Individual peds or clods were taken from each horizon for bulk density measurements and moisture retention and clods of known orientation were taken for thin-section study.

Physical Methods

Hydraulic Conductivity -- Undisturbed cores were taken with a typical double cylinder hammer driven core sampler. Laboratory analysis consisted of placing an undisturbed core on a screen with a beaker under the screen and a buret containing water over the core. A 1-cm head of water was maintained by allowing the core to drip water at the same rate the core was transmitting water.

Hydraulic conductivity was calculated by an equation similar to Darcy's law (Hillel, 1971 p. 82-85).

$$K = \frac{QH}{A\ (h + H)}$$

Where: Q is the volume of flow per unit time (cc/sec).

A is the cross-sectional area of the soil core ($44.16\ cm^2$).

K is the hydraulic conductivity (cm/sec).

h is the total head (1 cm).

H is the length of the core (7.62 cm).

Bulk Density -- Soil peds or clods were oven dried, weighed in air, coated with paraffin and weighed in water and in air. Corrections were made for weights of the paraffin and particles less than 2mm. Calculations are similar to those used by Brasher and others (1966).

Moisture Retention -- Water held against tension was measured at 1/3, 1, 5 and 15 atmospheres of pressure using pressure plates and membranes. Undisturbed clods were placed on a disc of fine soil (less than .05mm) to provide good contact between the clod and the plate. Samples were allowed to equilibrate for 48 hours.

Mechanical Analysis -- The less than 2mm material from each horizon was dispersed by shaking in a calgon solution for 24 hours after destruction of organic matter by 30% hydrogen peroxide and removal of dissolved mineral matter by filtration. The dispersed sample was washed on a 300-mesh sieve, passing the silt and clay through the sieve into a 1-liter cylinder. The dry sands were weighed, placed in a nest of sieves for fractionation and shaken for 3 minutes. The less than .02mm fraction was determined by the pipette method as described by Kilmer and Alexander (1949). The Paxton series for the Northampton site was analyzed twice to show the amount of variance in the method.

Thin Section Analysis -- Thin-sections of vertical orientation were made from undisturbed clods of the B22 and Cx horizons of Paxton fine sandy loam in Northampton. A thin section of a silt cap on a coarse fragment occurring in the fragipan of Millis fine sandy loam in Belchertown was also made. The samples were impregnated with a liquid plastic resin under vacuum according to the manufacturers recommendations (Chemical Coating and Engineering Co., St. Louis, Missouri). After hardening the samples were cut, mounted on standard petrographic slides and ground to optical thickness of approximately 30 microns.

The features were studied by means of a binocular polarizing microscope and classified according to the system described by Brewer (1964).

Clay Mineralogy -- Clay was separated from bulk samples by sieving and centrifugation according to the methods of Jackson (1956). Organic matter in the A horizons was destroyed with 30% hydrogen peroxide. Iron oxides were removed from B horizon samples by the sodium citrate-bicarbonate-dithionate method of Jackson (1956).

Clay mineralogy was determined by x-ray diffraction. Oriented mounts of the less than 1m fraction were prepared on glass slides or ceramic plates after the method of Kinter and Kimond (1956). All samples were treated as follows: air dried, K saturated, glycolated, heated to 325°C and heated to 550°C. Selected samples were also treated with na-citrate for 9 hours after the methods of Tamura (1958), Sawhney (1960) and Quigley and Martin (1963) to remove Fe and Al interlayer complexes. After Na-citrate treatment for 9 hours the samples were again treated with K. The A horizons of both soils were Mg-saturated and treated with glycerol after interlayer removal. A, B and C horizons of both soils were also treated with 1N HCl at 100°C for 1 hour and then K-saturated after interlayer removal.

A General Electric diffractometer equipped with a Cu-target x-ray tube, Ni K-beta filter and a proportional counter was employed. Linear scans from 2° to 32° 2θ at a rate of $2^{\circ}/2\theta$ min. were made with a 2 second time constant, medium resolution colimeters and 0.2° receiving slit.

Chemical Methods

Organic Carbon -- Organic carbon was determined by acid dichromate digestion. A 0.5 gm soil sample and 10 ml., of 1N potassium dichromate was placed in a 500 ml Erlenmeyer flask. Then 20 ml of concentrated sulfuric acid was added rapidly. After cooling for 30 minutes 200 ml of water, 10 ml of phosphoric acid, and 0.5 ml of barium dephenylaminesulfanate indicator were added. The solution was then titrated with ferrous sulfate to determine the percent organic carbon by the following equation (Peech and others, 1947):

$$\% \ C = \frac{(\text{ml } 1 \text{ N } K_2Cr_2 07 \text{ reduced})\ (0.39)}{.5 \text{ gm}}$$

Exchangeable Cations -- Exchangeable metal cations were extracted from a 25-gm soil sample by leaching the sample under gentle suction with approximately 200 ml of 1 N ammonium acetate through Whatman No. 42 filter paper (Peech and others, 1947). The leachate was transferred to a volumetric flask and analyzed for exchangeable calcium, magnesium, sodium, and potassium by atomic absorption. Exchangeable hydrogen was determined by subtracting the total exchangeable metal cations from the cation exchange capacity. Base saturation was calculated by dividing the exchangeable metal cations into the cation exchange capacity.

Cation Exchange Capacity -- Cation exchange capacity was determined by Nesslerization of absorbed ammonia after extraction with sodium chloride (Peech and others, 1947).

The ammonium saturated soil samples used to determine exchangeable cations were washed with alcohol to remove the excess of ammonium acetate. The samples were then leached with approximately 200 ml of 10 percent sodium chloride solution. The leachates were transferred to volumetric flasks. Aliquots of the leachate solutions were compared to standard NH_4Cl solutions after Nesslerization with the aid of a Bausch and Lomb Spectronic 20 Spectrophotometer.

pH -- A 1 : 1 soil to water by weight solution was thoroughly mixed and allowed to equilibrate for one hour at room conditions. The solution was then mixed again and pH measured with a Beckman model 1019 pH meter.

RESULTS

Following are the descriptions of the two profiles which have been subjected to detailed field and laboratory studies. The descriptive terminology used is that given in the Soil Survey Manual, Soil Survey Staff (1951).

Description of Paxton

Soil Type:	Paxton extremely stony fine sandy loam.
Classification:	Typic Fragiochrepts
Location:	Hampshire County, Massachusetts. Deep borrow pit. 5000 feet west of the intersection of Sylvester and Turkey Hill Roads on the south side of Turkey Hill Road. Wzorek's gravel pit, Easthampton quadrangle, Massachusetts (Fig. 6). Longitude - 72°44'15" Latitude - 42°18'30"
Vegetation and Land Use:	Forest - Red Maple, American Elm, Hemlock, Mountain Laurel.
Slope:	3 percent south.
Physiography:	Base of drumloidal hill.
Parent Material:	Unsorted debris, possibly lower till or colluvium developed mainly from mica schist and other metamorphic rocks.

Horizon	Depth Inches/Centimeters	Description
A_1	0-5/0-13	Very dark grayish brown (10YR3/2) extremely stony fine sandy loam; weak fine granular structure; very friable; many fine, medium, and coarse tree roots; pH 4.6; abrupt wavy boundary.
B_{21}	5-14/13-33	Dark yellowish brown (10YR4/4) fine sandy loam; massive structure; very friable; many fine and medium coarse tree roots; pH 5.4; gradual wavy boundary.
B_{22}	14-22/33-60	Dark grayish brown (10YR4/2) fine sandy loam; moderate medium weak platy structure; friable; many

Horizon	Depth Inches/Centimeters	Description
		medium tree roots; pH 4.81; abrupt smooth boundary.
B_{23}/Cx_1	22-42/60-125	Olive gray (5Y4/2) fine sandy loam; strong medium platy structure; extremely firm; peds contain discontinuous pores approximately 0.1 mm in diameter; nearly vertical planar cracks approximately 25 mm in width begin at the lower boundary of the B_{22} and are common throughout the Cx_1. The cracks are about 12 to 18 inches apart at a depth of 22 inches and less than 6 inches apart at a depth of 22 inches and less than 6 inches apart at 42 inches. When viewed in plan, the cracks form crude polygons. Center of the cracks are uniform gray (5YR5/6); borders are yellowish brown 10YR5/6; few fine and medium tree roots are present only in the cracks; diffuse irregular boundary.
B_{23}/Cx_2	42+/125+	This horizon is similar to the Cx_1 except that the platy structure is coarser, and discontinuous pores are present only along lines of fissility. Cracks are less than 6 inches apart and become difficult to trace at this depth. A reddish brown (7.5YR4/4) deposit (possibly hematite) occurs on all plate surfaces. This deposit also occurs in the Cx_1 but becomes increasingly more evident with depth.

Description of Millis

Soil Type:	Millis fine sandy loam.
Classification:	Typic Fragiochrepts.
Location:	Hampshire County, Massachusetts. Deep borrow pit. 1000 feet northeast of intersection of Hannum and Jackson Streets, on the north side of unnamed road (Figs. 7 and 8). Longitude - 72°17'45" Latitude - 42°25'10"
Vegetation and Land Use:	Old pasture - Staghorn Sumac, Gray Birch.
Slope:	3 percent west.
Physiography:	Ground moraine.
Parent Material:	Upper glacial till developed mainly from gneiss and other well decomposed amphiboltic metamorphic rocks with a small percentage of sedimentary rocks.

Horizon	Depth Inches/Centimeters	Description
A_1	0-8/0-20	Dark brown (7.5YR3/2) fine sandy loam; weak, very fine granular structure, very friable; many fine and medium roots; pH 4.95; abrupt smooth boundary.
B_{21}	8-20/20-50	Strong brown (7.5YR5/6) fine sandy loam; massive structure, very friable; many fine and medium roots; pH 5.06; gradual wavy boundary.
B_{22}	20-30/50-75	Yellowish brown (10YR5/4) fine sandy loam; massive structure; friable; many fine and medium roots; pH 5.82; abrupt smooth boundary.
ICx	30-61/75-155	Olive gray (5Y5/2) loamy sand; weak medium platy structure; firm; peds contain numerous 1 mm to

Fig. 6 Paxton study site, Northampton.

Fig. 7 Millis study site, Belchertown.

Fig. 8 Profile of Millis. Note large rotten stone. Belchertown.

Horizon	Depth Inches/Centimeters	Description
		0.1 mm discontinuous pores; coarse fragments are coated with silt and lie in beds of sand; mottled streaks (5Y6/1 and 10YR5/6) are present in places; very few medium roots are present, pH 6.15; abrupt smooth boundary.
IICx	61+/155+	Olive gray (5Y4/2)loamy sand; massive structure; firm to friable; contains more skeleton than ICx; roots are rare; pH 6.18.

Hydraulic Conductivity -- The average hydraulic conductivity on 4 core samples from each horizon measured is given in Table 1. Values decrease sharply in the fragipans. The replicate cores of the fragipans compared to other horizons, show the largest variability in hydraulic conductivities. Their values are as extreme as .01 to .46 in./hr. The variability in hydraulic conductivity in the fragipan is due to the presence of cracks and coarse fragments in some cores, while in others they are absent.

Bulk Density -- Bulk density of the fragipans is much higher than the A and B horizons (Table 1 and Fig. 9). Bulk density of the polygonal crack material in Paxton at Northampton is approximately .2g/cc less than the fragipan matrix. The percent of pore space also decreases with depth in the profiles (Table 1).

Moisture Retention -- Both percent water by volume and the percent water filled pores i.e., percent water by volume ___ percent pore space, in both soils are greater in the C horizons than in the B horizons (Table 1 and Figs. 10 and 11).

Mechanical Analysis -- Mechanical analyses are presented in Table 2 and

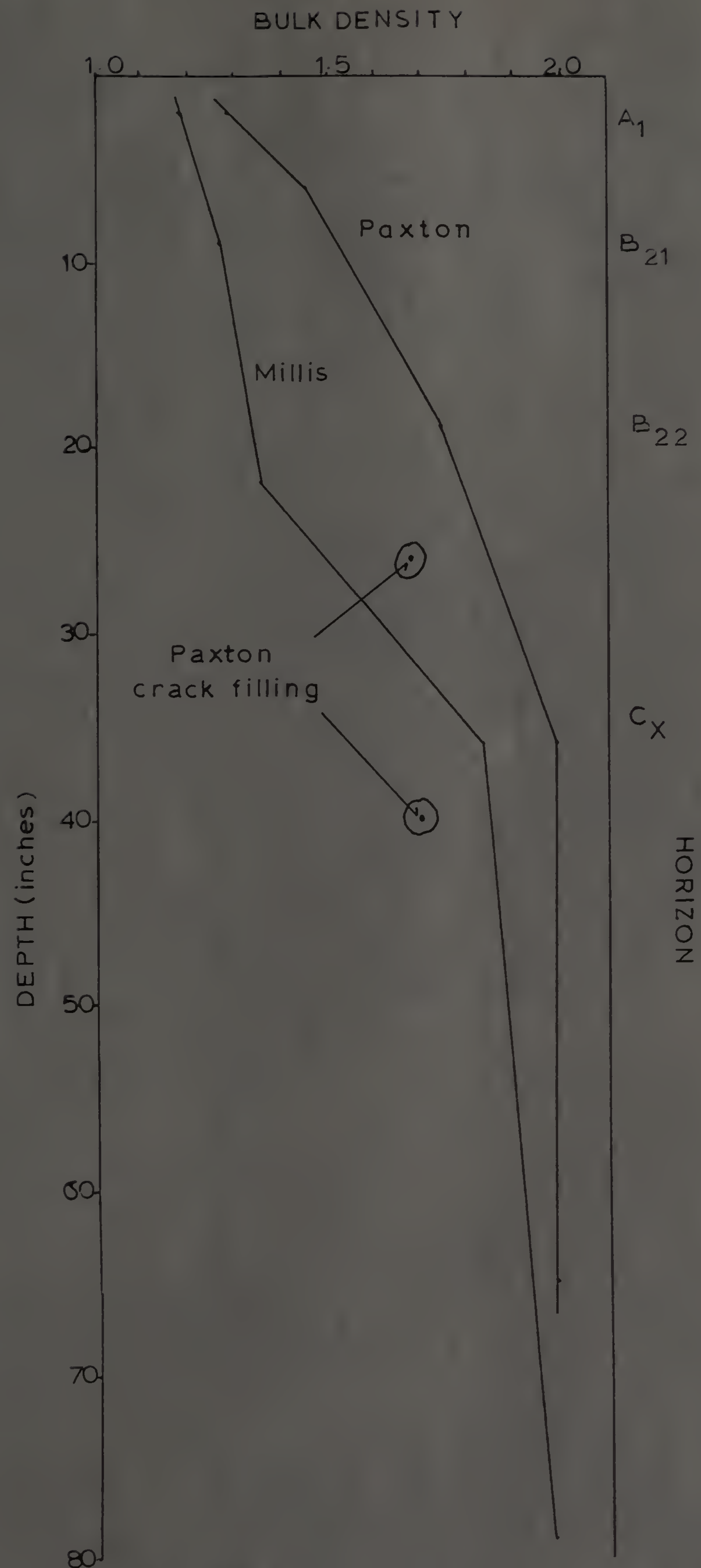
TABLE 1 Physical Properties of the Profiles

Horizon	Depth (in)	Bulk Density (gm/cc)	%Pore Space	Hydraulic Conductivity	%Moisture Volume (atmospheres)				
				in./hr	$\frac{1}{3}$	1	5	15	Field Moist
				Paxton - Northampton					
A1	2	1.28	51.70	____	11.9	20.1	13.8	10.4	56.1
A1 rehardened	2	1.81	31.70	____	____	____	____	____	____
B21	6	1.45	45.28	3.65	____	____	____	____	____
B22	19	1.74	34.34	0.52	20.0	11.8	9.6	7.8	28.71
Cx1	36	1.89	28.68	0.33	26.1	20.9	16.6	12.1	28.90
Cx1 rehardened	36	1.72	35.09	____	____	____	____	____	____
Cx2	65	1.88	29.06	____	____	____	____	____	____
Crack	26	1.67	36.98	____	____	____	____	____	____
Crack	60	1.69	36.23	____	____	____	____	____	____
Till Ball	144	2.01	24.15	____	____	____	____	____	____
Unoxidized Till	240	1.98	25.28	____	____	____	____	____	____

TABLE 1 (continued)

Millis - Belchertown

Ap	2	1.18	55.47	____	____	____	____	____	23.4
B_{21}	9	1.27	52.08	____	____	10.7	____	6.7	20.6
B_{22}	22	1.35	49.06	5.76	11.8	10.3	8.4	6.2	12.7
ICx	36	1.83	30.94	5.10	12.9	11.0	6.2	6.6	17.2
ICx rehardened	36	1.72	35.09	0.73	____	____	____	____	____
ICx rehardened	36	1.84	30.57	____	____	____	____	____	____
IICx	79	1.88	29.06	____	____	____	____	____	____



The fragipans have high bulk density relative to the horizon's above.

Fig. 9

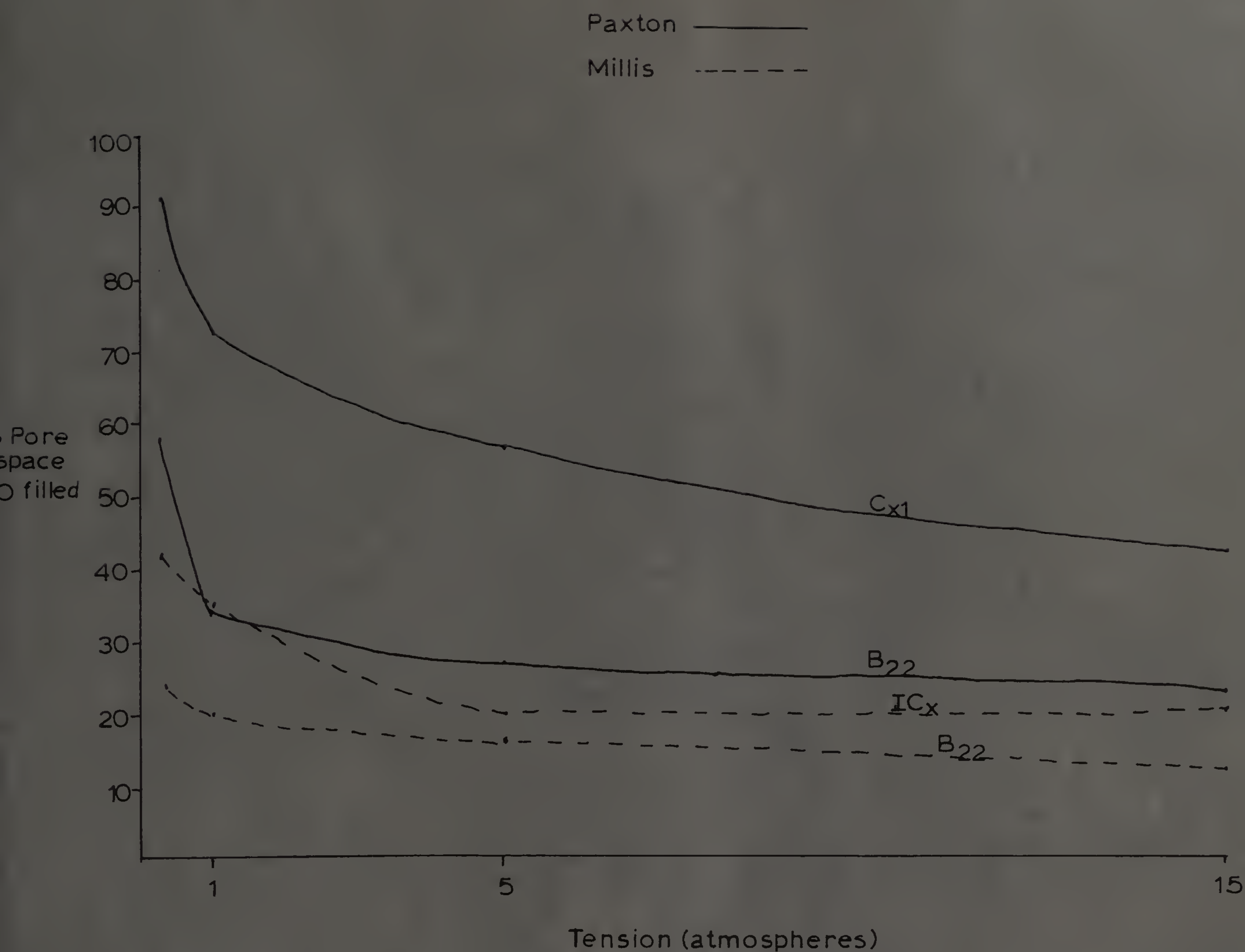
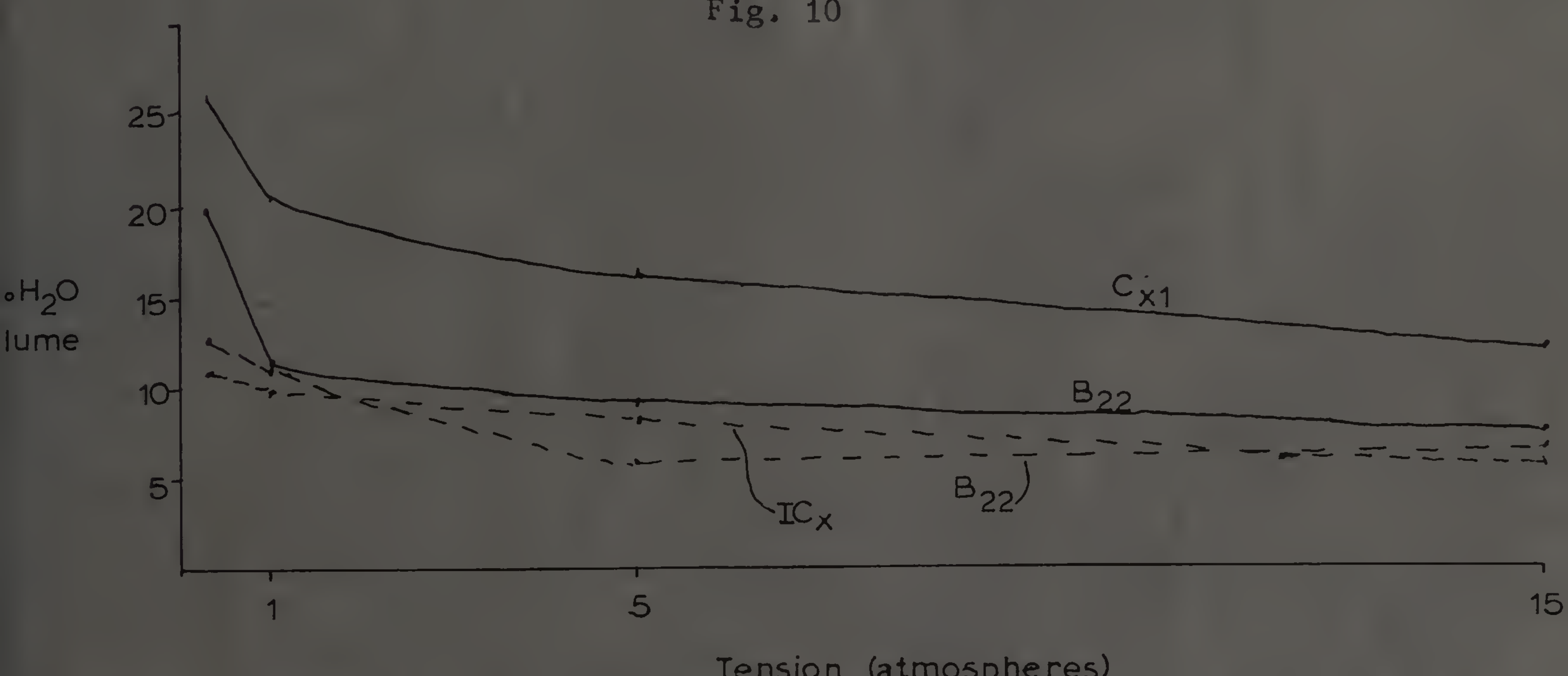


Fig. 10



Moisture retention is generally greater in the fragipans than in the B_{22} horizons.

Fig. 11

Figs. 12 and 13. A slight decrease in silt and clay with depth occurs in the Millis profile. An increase in silt and clay with depth occurs in the Paxton profiles. There is an increase in the sand fraction of the Millis profiles. The sand fractions of the Paxton profiles are uniform except for a sand lens in the Cx1 horizon which has been described as an A_2 horizon in Table 2. Sand lenes are common in the till at Northampton.

Silt caps, sand beds and polygonal crack fillings all deviate from the particle size distribution of horizon matrices.

Silt caps in the Millis profile in Belchertown show an increase of 8% clay and 16% silt when compared to the fragipan matrix. The sand beds show increases of 9% sand and a decrease of 5% silt.

Polygonal crack material of the Paxton fragipan in Northampton show a 5% increase in sand and a 4% decrease in silt.

Thin Section Analysis -- Descriptive terminology of thin sections follows that of Brewer (1964).

The matrix fabric of the fragipan and B_{22} horizon of Paxton at Northampton are silasepic i.e., they have a lack of plasma separation. Pores of the fragipan and B_{22} matrices are clean and lack clay cutans. Pores of the B_{22} and fragipan matrices are described as mammillated vughs i.e., they are relatively large voids, not interconnected and have rounded smooth walls (Figs. 14, 15, 16, 17 and 18).

The most striking feature of the fragipan in Paxton is the oriented clay (cutans) present on all ped surfaces. Associated with the ped surfaces are vesicles. The vesicles are of a near uniform size and spherical shape (Figs. 19 and 20).

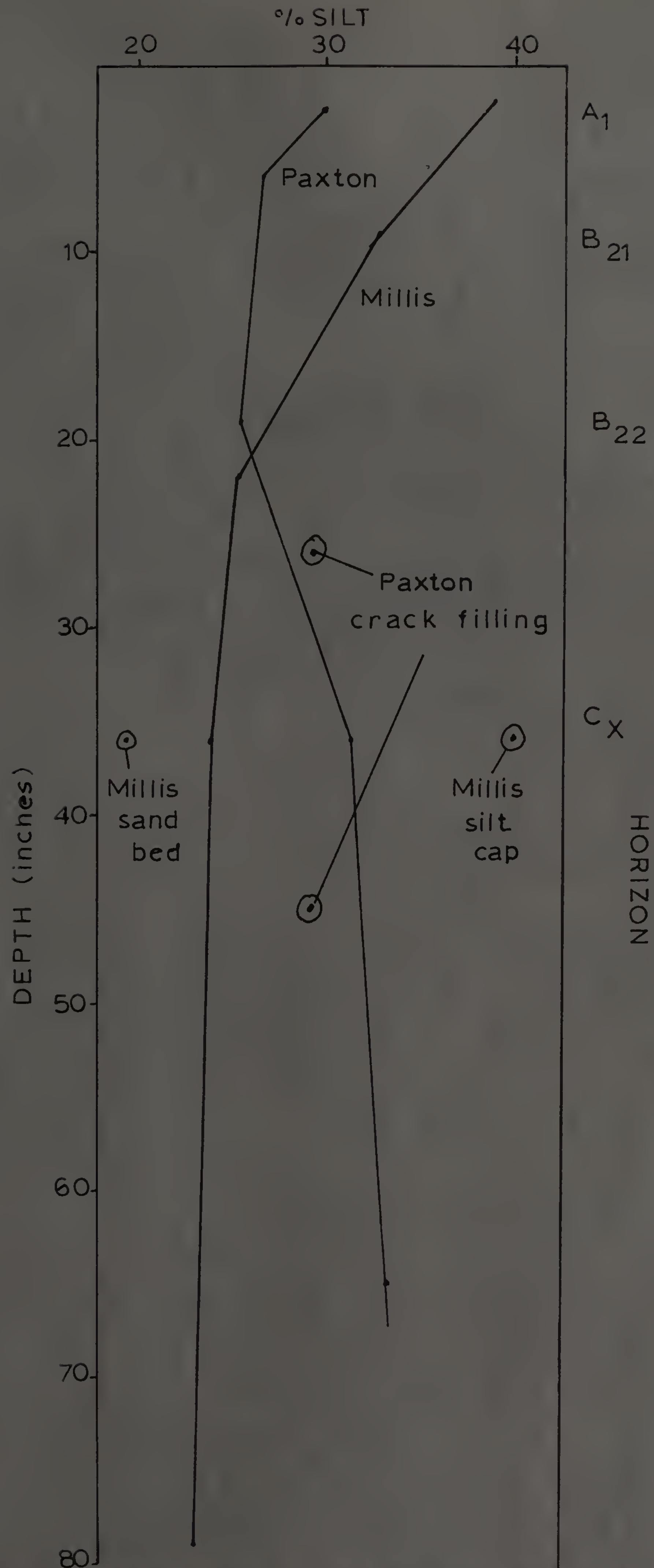
A vertical micro-joint was observed at 79 inches. Hematite formation was noted in places on both sides of vertical joint. The frequency of the

TABLE 2 Mechanical Analysis of the Paxton Series in Milimeters

Horizon	Depth in inches	Sand 2-0.05	Silt 0.05-0.002	Clay .002	Sand: Very Coarse 2-1	Sand: Coarse 1-0.5	Sand: Med. 0.5-0.25	Sand: Fine 0.25-0.1	Sand: Very Fine 0.1-0.05	0.05-0.02	Int III 0.02-.002	Int II 0.2-.02	Int I 2-0.2
Paxton - Northampton													
A_1	2	60.63	29.98	9.39	7.71	8.60	21.37	12.64	10.31	17.02	12.96	39.97	37.68
		60.16	30.83	9.01	5.58	8.72	21.18	12.46	11.85	16.88	13.96	41.19	35.85
B_{21}	6	65.44	26.61	7.95	7.07	9.33	21.59	13.40	14.05	15.31	11.30	42.76	37.99
		65.64	27.51	6.85	6.77	9.53	21.34	13.41	14.69	15.03	12.48	43.03	37.64
B_{22}	19	64.97	25.43	9.60	7.16	8.81	19.90	13.20	15.90	14.16	11.27	43.26	35.87
		65.85	24.78	9.37	6.35	8.73	20.69	13.79	16.28	14.12	10.65	44.20	35.77
A_2	20	84.40	8.18	7.42	19.96	24.45	18.94	15.13	5.60	4.06	4.12	17.15	71.31
Cx1	36	56.04	31.21	12.75	5.34	8.53	18.35	11.34	12.48	14.88	16.13	38.70	32.22
		53.13	33.94	12.93	4.61	7.24	18.38	11.21	11.69	14.08	19.86	36.98	30.23
Cx2	65	54.65	33.33	12.02	5.55	7.66	17.84	11.15	12.45	15.52	17.82	39.12	31.05
		53.11	34.15	12.74	5.80	6.89	16.80	10.83	12.79	16.42	17.73	40.04	29.49
Crack	26	60.27	28.26	11.47	4.45	7.72	11.36	20.80	15.93	13.23	15.03	41.59	31.90
Crack	60	61.30	19.09	9.61	5.88	7.87	11.72	20.36	15.51	13.87	15.22	41.39	33.78
Unoxidized Till	240	52.34	30.48	17.18	5.78	6.31	15.51	10.13	14.61	14.95	15.53	39.69	27.60

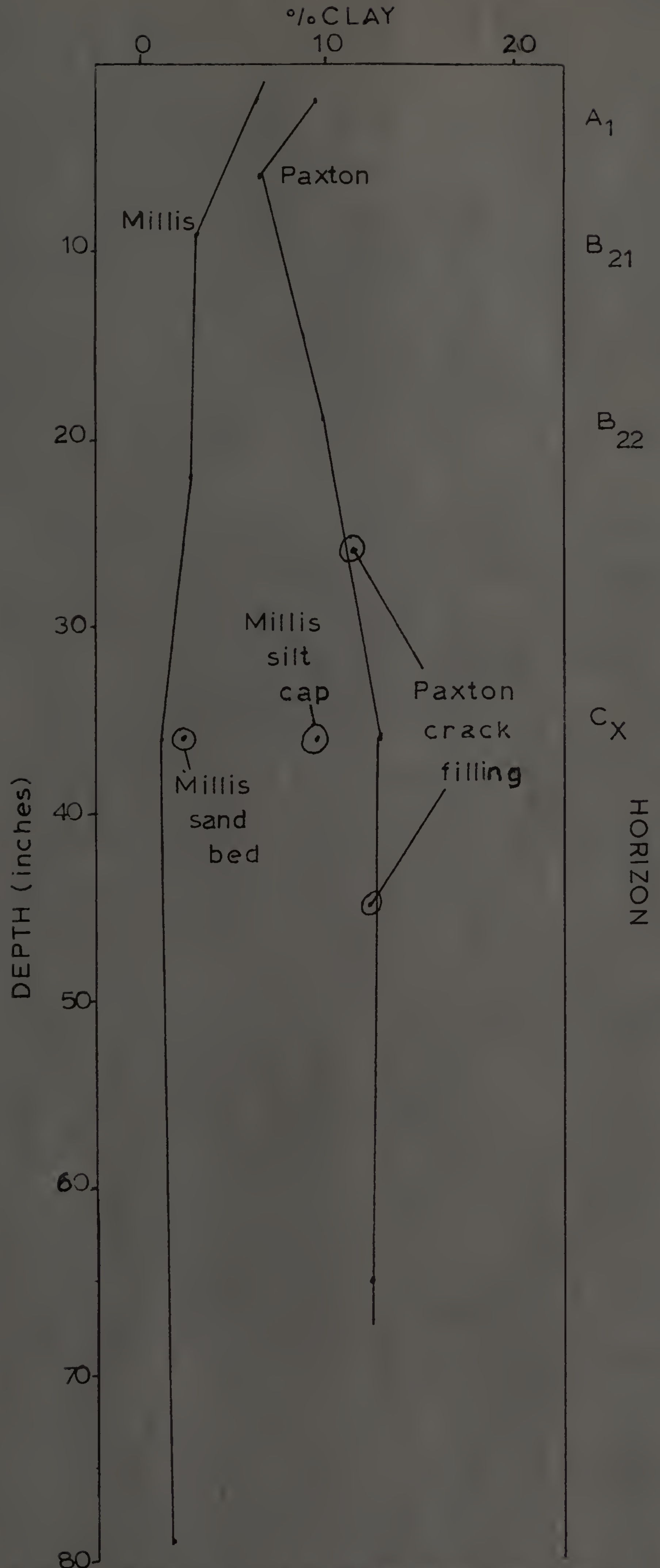
TABLE 2 (continued)

Till Ball	144	60.39	34.36	5.25	4.47	6.34	18.44	12.60	18.54	15.38	18.98	45.82	29.25
Till Above Ball	124	65.34	18.92	15.74	7.98	10.45	20.16	11.78	14.91	14.08	4.84	40.83	38.59
Millis - Belchertown													
A_1	2	54.66	38.99	6.35	3.94	7.93	20.71	7.51	14.57	22.68	16.31	44.76	32.58
B_{21}	9	64.03	32.94	3.03	4.72	11.65	25.79	9.25	12.62	19.13	13.81	42.16	41.00
B_{22}	22	71.92	25.35	2.73	8.16	11.74	26.58	11.54	13.90	9.75	15.60	35.19	46.48
ICx	36	74.93	23.93	1.15	9.17	12.78	28.27	11.58	13.13	12.42	11.51	37.13	50.22
IICx	79	75.46	22.86	1.68	7.35	11.80	30.74	12.74	13.10	11.50	11.36	37.03	49.89
Silt Cap	36	50.75	39.84	9.41	3.29	6.36	16.08	9.23	15.79	19.38	20.46	25.73	44.40
Sand Bed	36	83.71	18.32	2.03	10.79	14.22	31.20	13.22	14.28	13.85	4.47	56.21	37.29



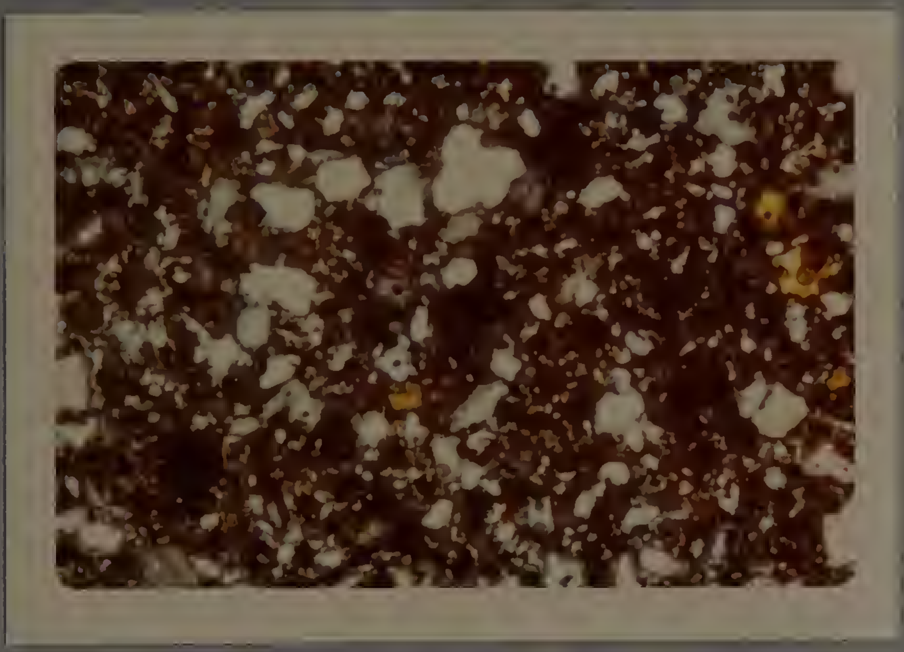
Percent silt increases with depth in Paxton (percent silt of the crack remains constant). Percent silt decreases with depth in Millis.

Fig. 12



Percent clay increases with depth in Paxton.
Percent clay decreases with depth in Millis.

Fig. 13



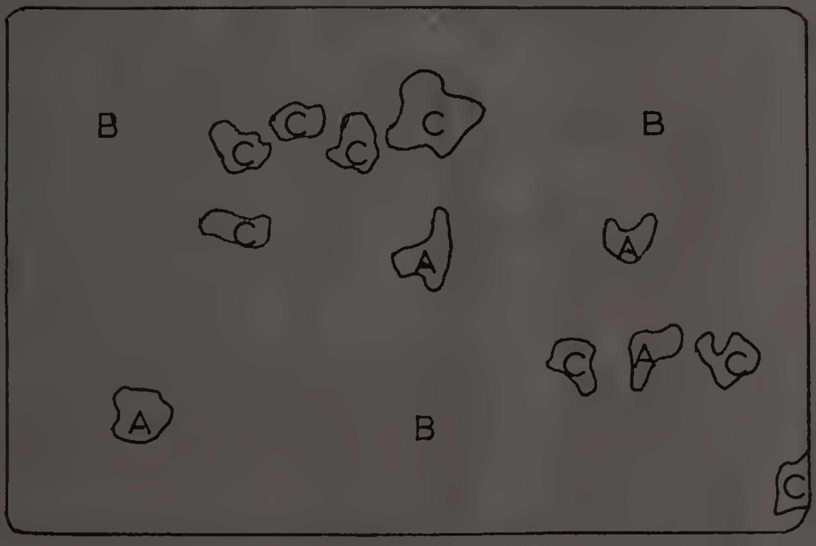
Paxton B_{22} horizon matrix

16 inches

Crossed Polarizers

Magnification 40x

Fig. 14



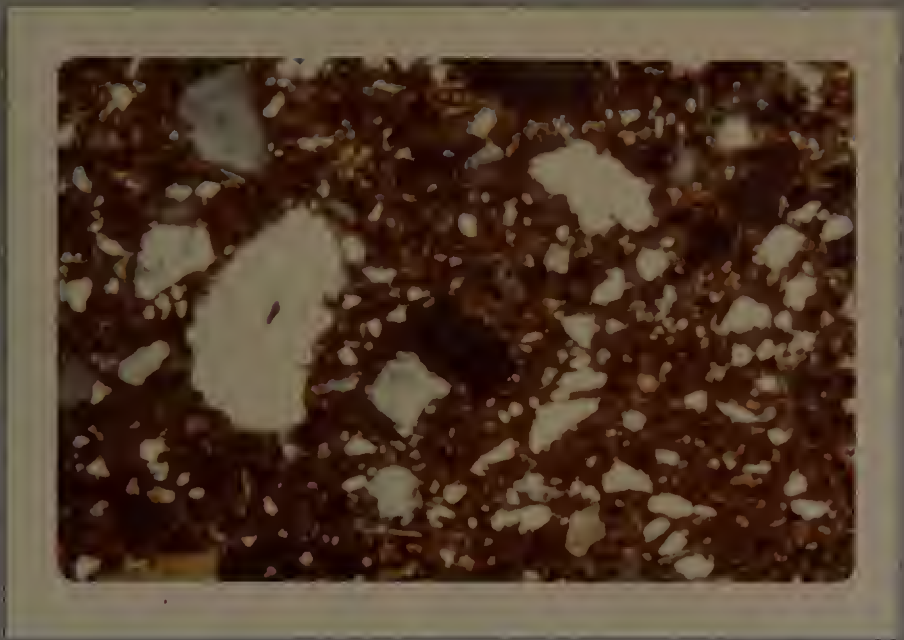
A. Pores

B. Non-oriented soil matrix

C. Quartz or feldspar grains

Fig. 15

Pores of the Paxton B_{22} horizon are clean.
The matrix is silaseptic.



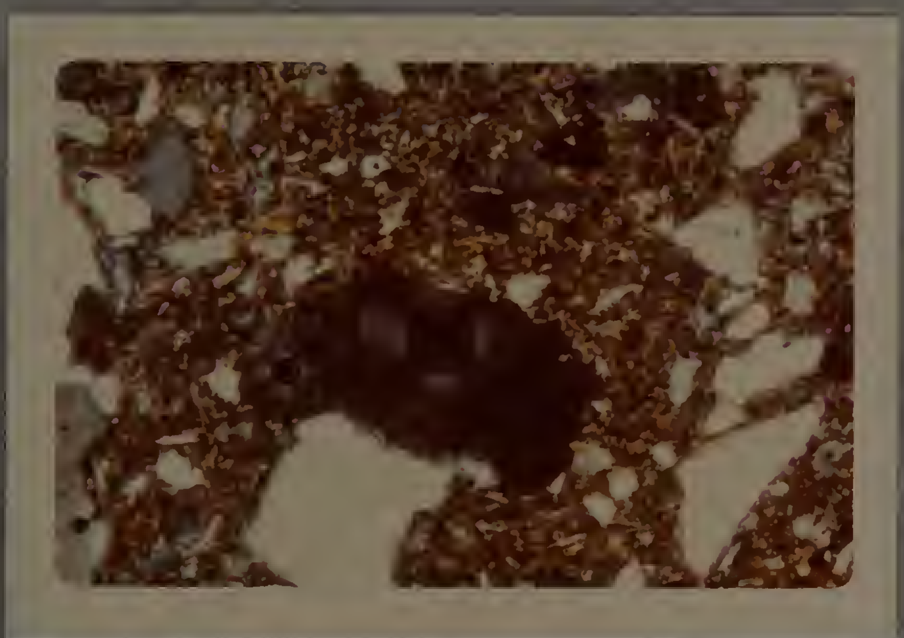
Paxton Cx_1 horizon matrix

30 inches

Crossed Polarizers

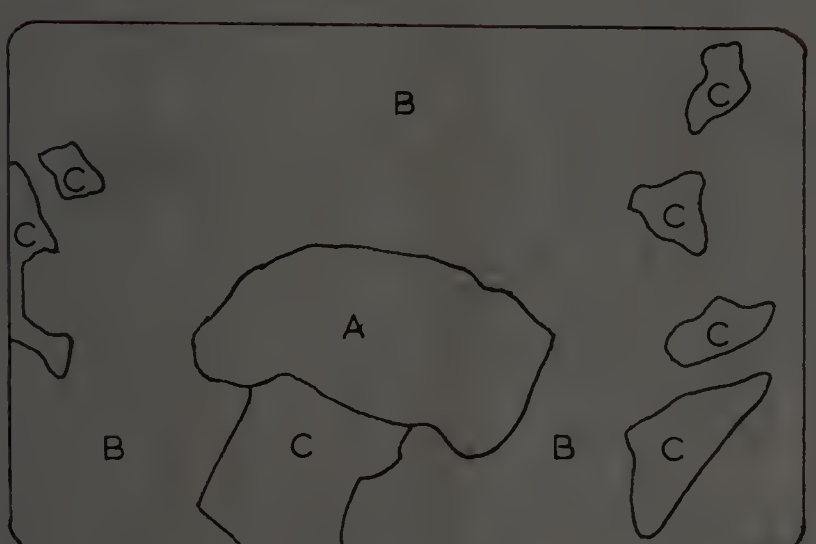
Magnification 40x

Fig. 16



Magnification 160x

Fig. 17



A. Pore

B. Non-oriented soil matrix

C. Quartz or feldspar grains

Fig. 18

Pores of the Paxton Cx_1 horizon are clean.
The matrix is silaseptic.

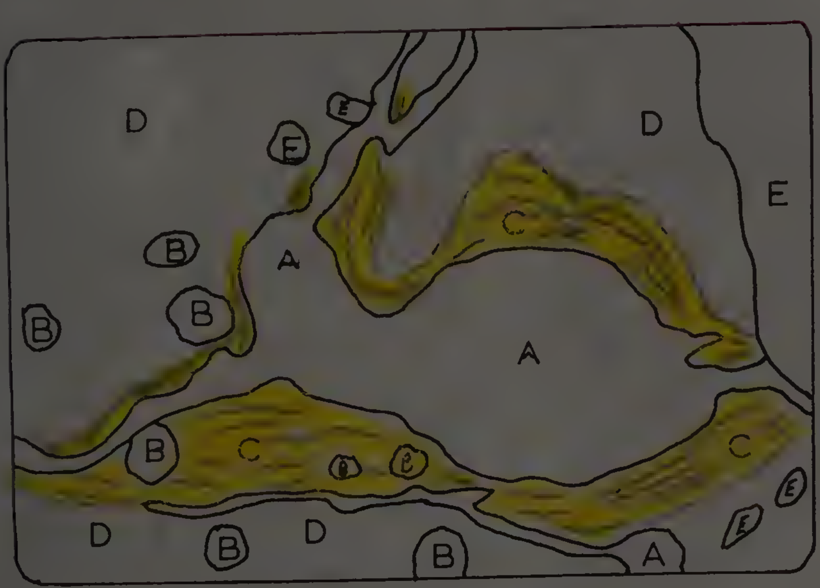
Paxton Cx_2 horizon, ped face

60 inches

Crossed Polarizers

Magnification 160x

Fig. 19



A. Pore

B. Air bubble

C. Oriented clay

D. Non-oriented matrix

E. Quartz or feldspar grains

Fig. 20

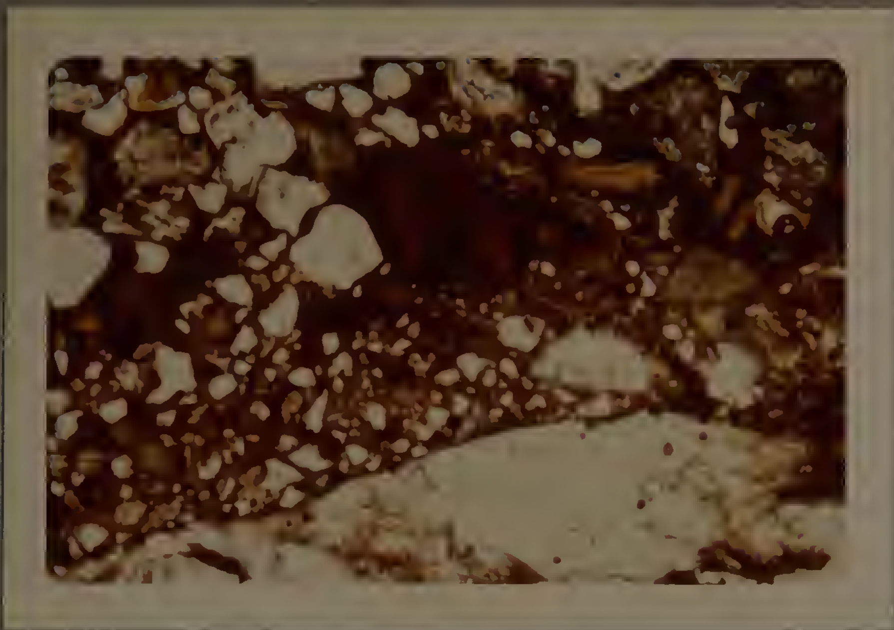
Ped faces of the Paxton Cx_2 horizon have pores and are lined with oriented clay.

vertical micro-joints is not known.

The matrix of unoxidized glacial till taken at a depth of approximately 15 feet from a borrow pit at Thomaston Dam Connecticut also is silasepic. However, pores are virtually absent and the structure is massive. The continuum of all horizons and till is silt and clay. Grain to grain contacts in the fragipan and till are very rare.

A thin-section of a coarse fragment with a silt cap from the fragipan of Millis at Belchertown consists of two distinct layers. Adjacent to the coarse fragment is a thin band of silt and clay, perhaps 0.5 mm. On top of the silt and clay band is a slightly thicker coarse band. Pores are rare and all grains are clean and lack cutans in the bands (Figs. 21, 22 and 23).

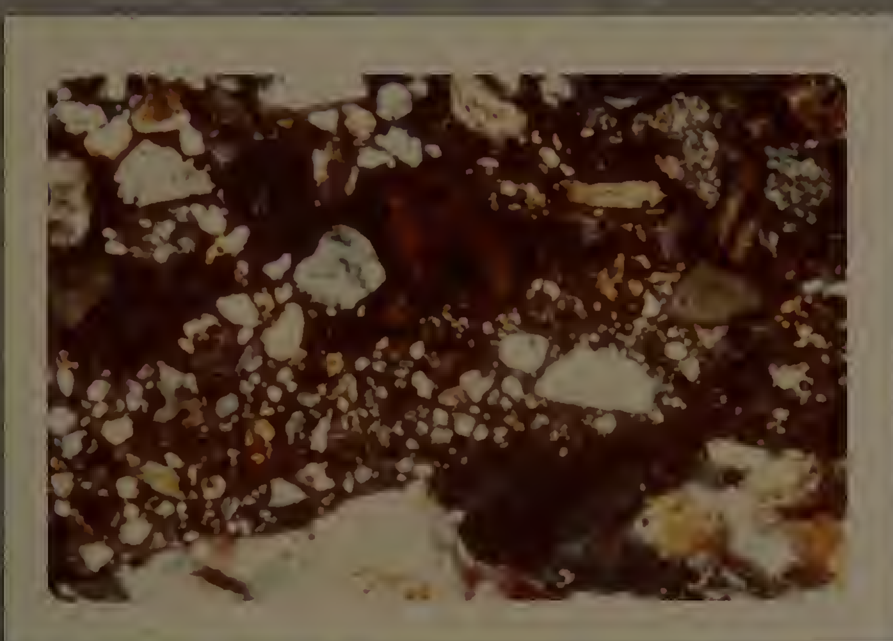
Clay Mineralogy -- X-ray diffraction patterns of the clays of the Paxton and Millis soils are shown in Figs. 24, 25, 26, 27, 28, 29 and 30. Both soils exhibit a distinct pattern of weathering. The intensity of the 14Å peak increases and the 10Å peak decreases with proximity to the surface (Figs. 24 and 25). This is interpreted as mica (10Å) weathering to vermiculite (14Å). Identification of the 14Å peak was possible only after Fe and Al interlayer complexes were removed by Na-citrate extraction for 9 hours. As seen in Fig. 26 no significant changes occur in either the 14Å or 10Å peak using conventional treatments i.e., glycol, K saturation and heat. After interlayer removal and K saturation the 14Å peak in Paxton samples collapse to 10Å; upon Mg-saturation and glycerol in both Millis and Paxton, no expansion of the 14Å peak occurs (Fig. 27). This behavior indicates that the 14Å peak in Paxton is chloritized vermiculite. After similar treatments in the Millis samples, a 14Å peak remains. The



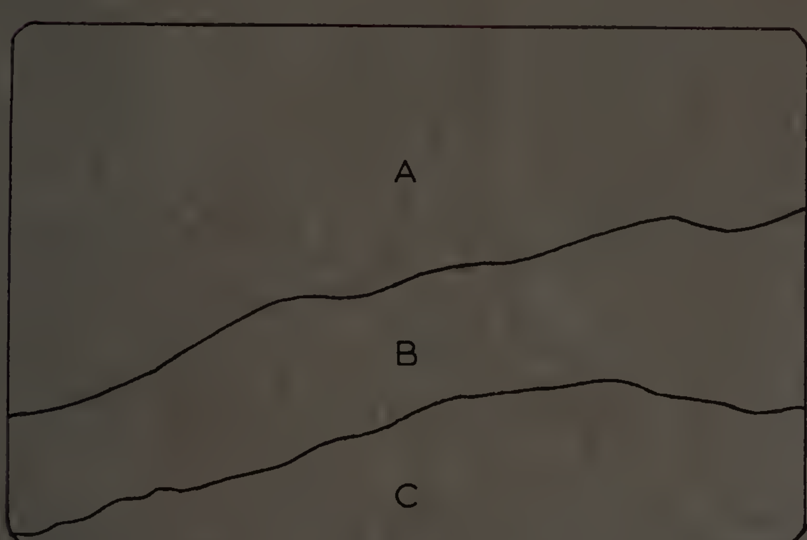
Magnification 40x Plain light
Fig. 21

Millis silt cap

36 inches



Magnification 40x Crossed polarizers
Fig. 22



A. Sand grains

B. Silt cap

C. Gniess fragment

Fig. 23

Silt caps in the ICx horizon of Millis have a silt band adjacent to the coarse fragment. Immediately above the silt band fines are uncommon.

Paxton
No treatment

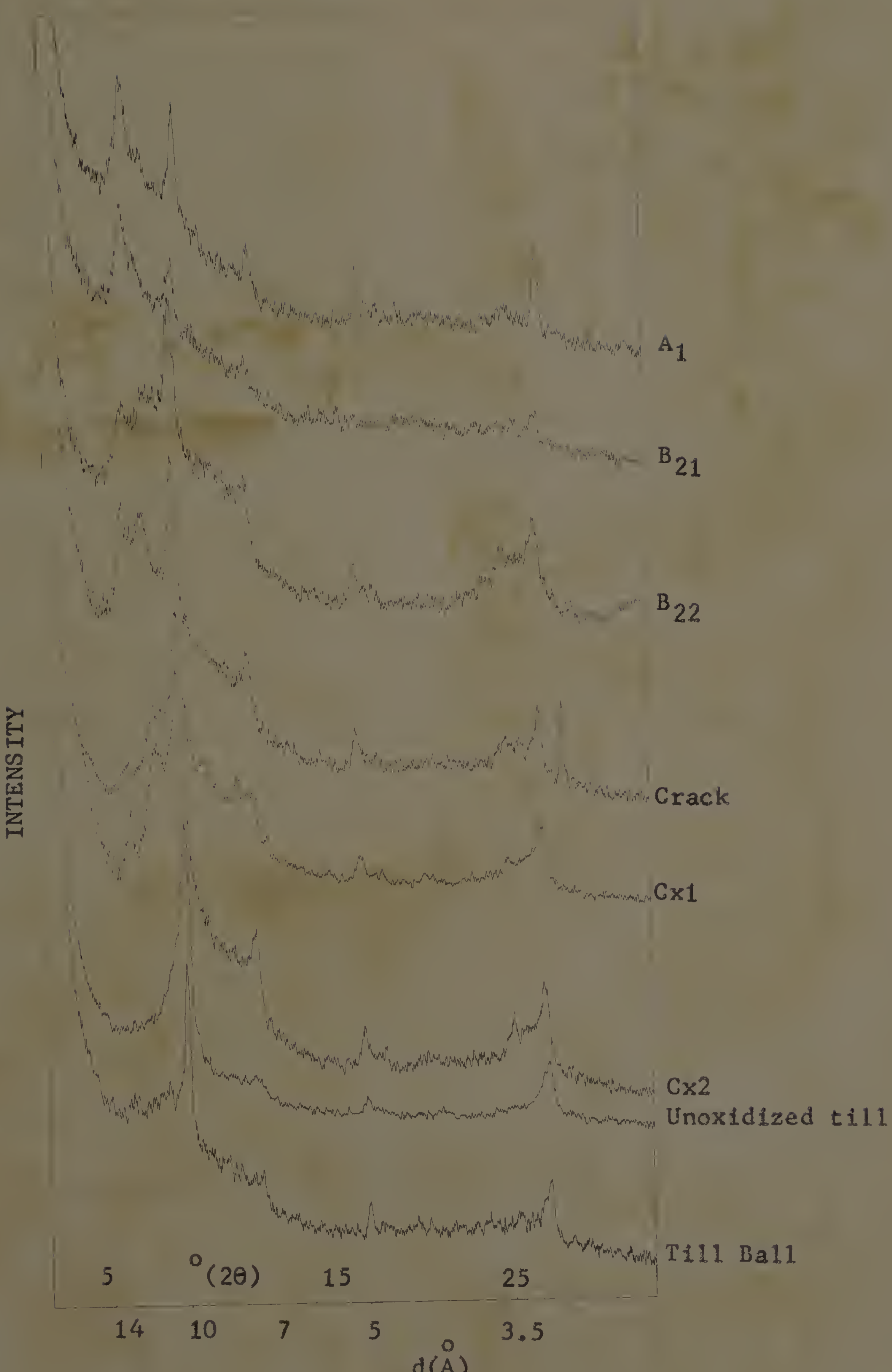


Fig. 24

Millis
No treatment

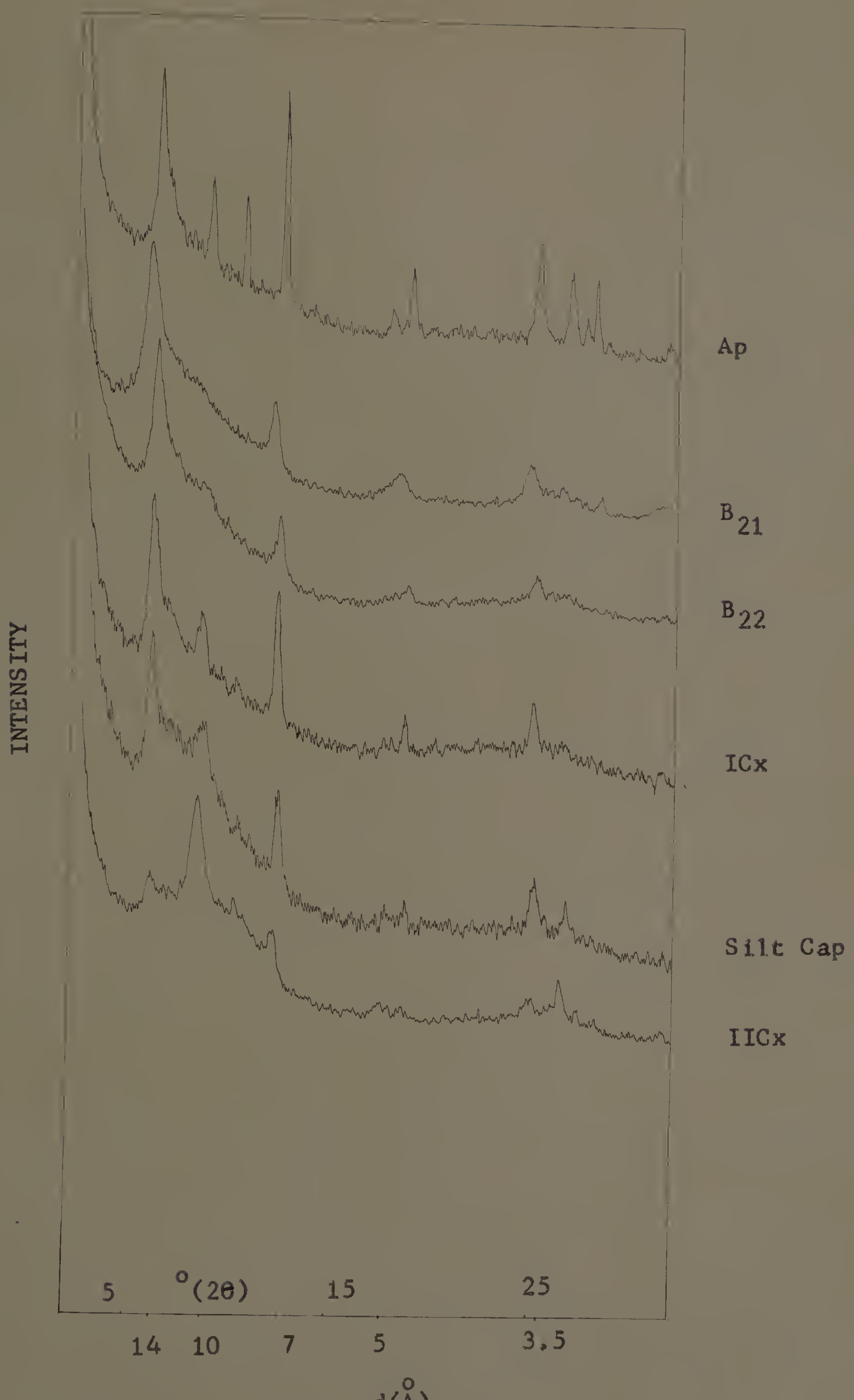


Fig. 25

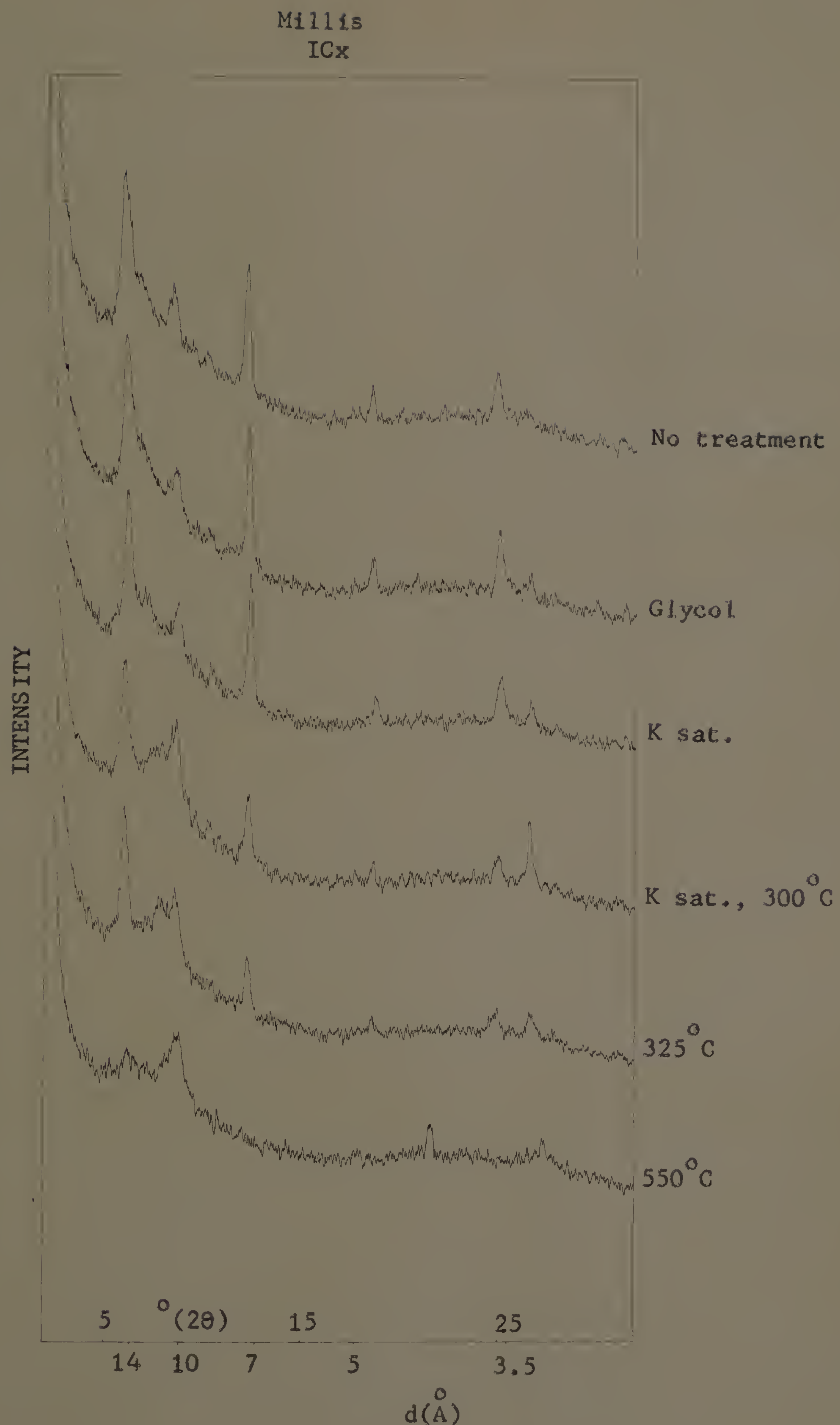

Millis
ICx
INTENSITY
No treatment
Glycol
K sat.
K sat., 300°C
325°C
550°C
5
°(2θ)
15
25
14
10
7
5
3.5
d(Å)

Fig. 26

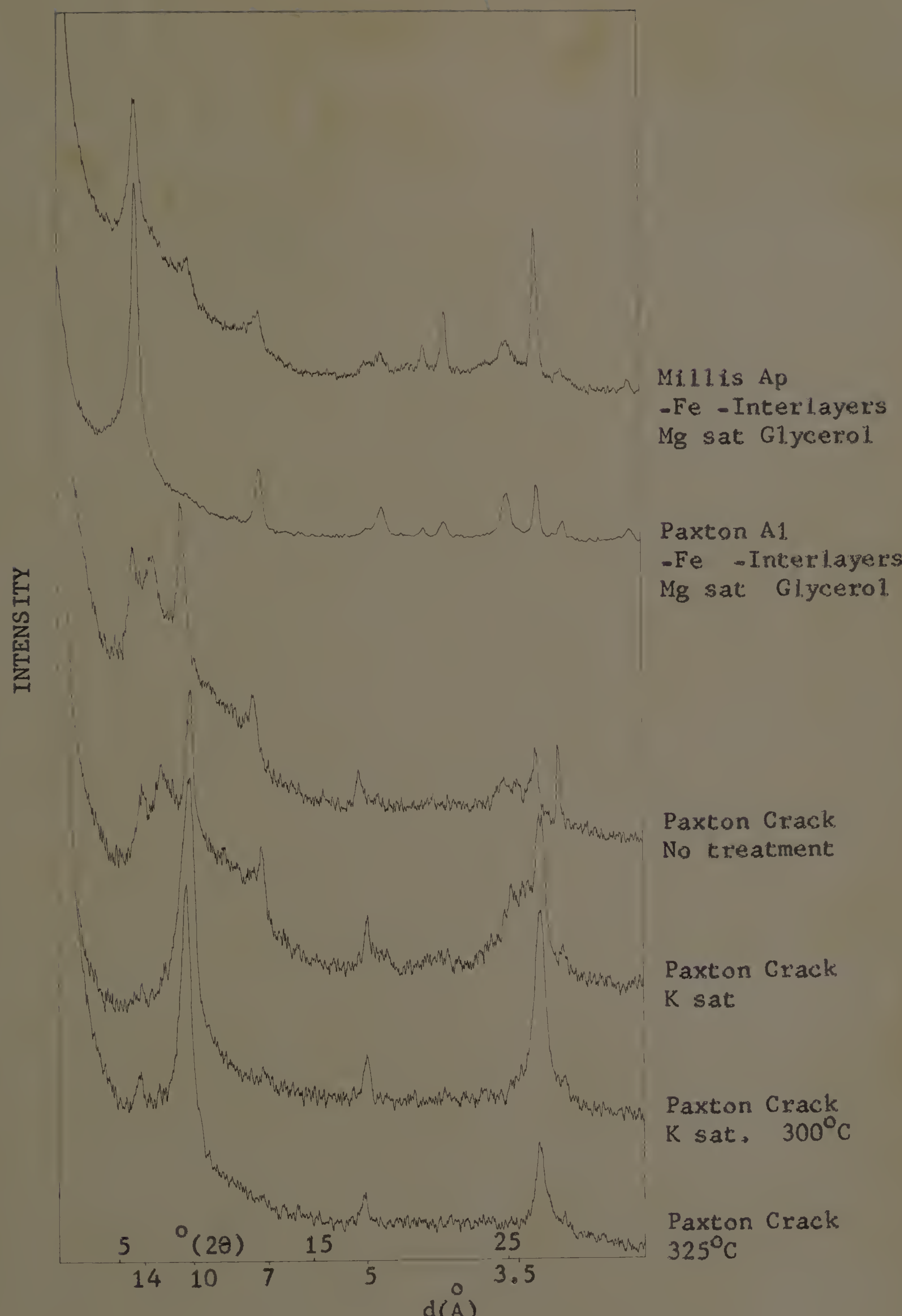

INTENSITY
Millis Ap
-Fe -Interlayers
Mg sat Glycerol
Paxton A1
-Fe -Interlayers
Mg sat Glycerol
Paxton Crack
No treatment
Paxton Crack
K sat
Paxton Crack
K sat, 300°C
Paxton Crack
325°C
5
°(2θ)
15
25
14
10
7
5
3.5
d(Å)

Fig. 27

Millis
ICx

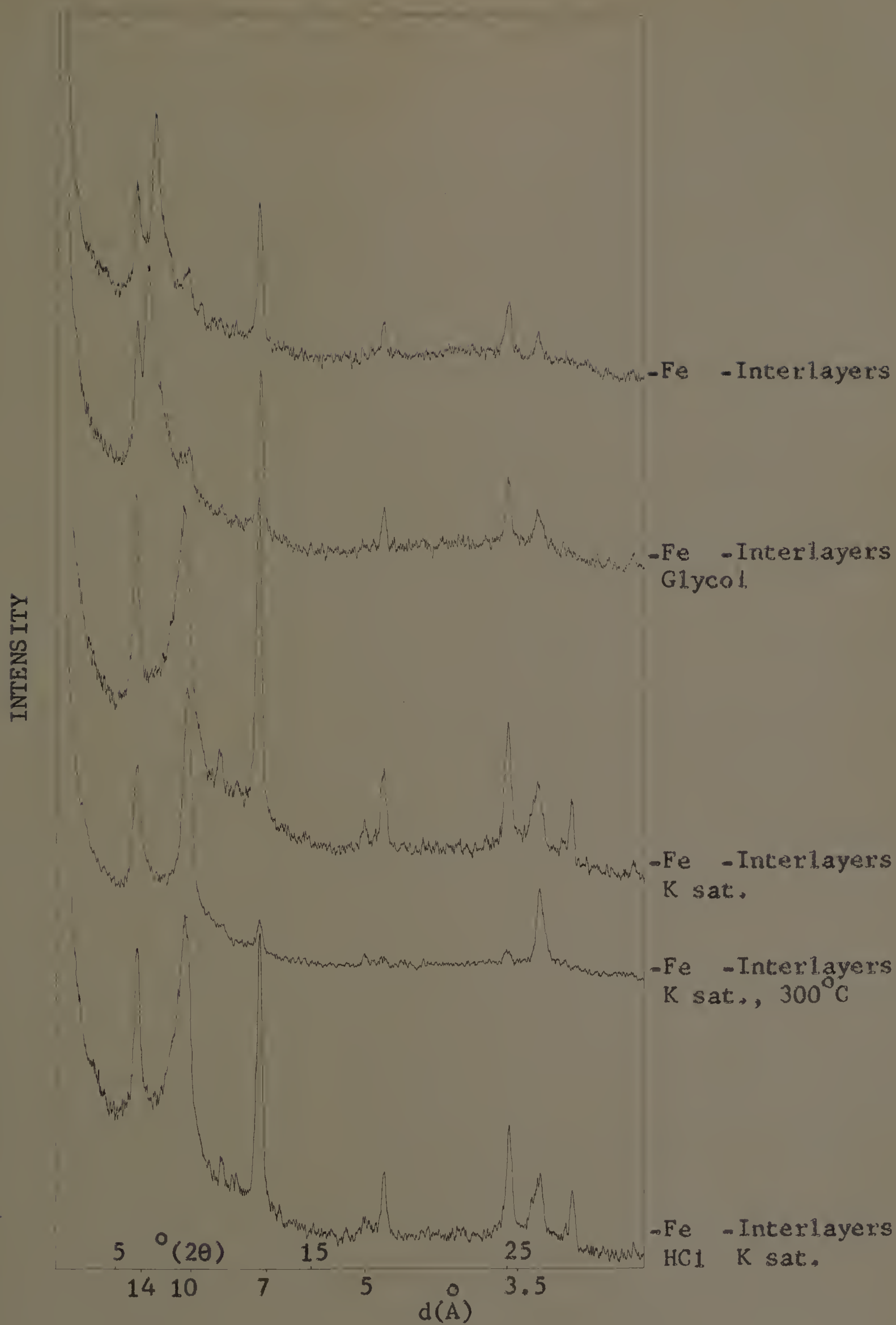


Fig. 28

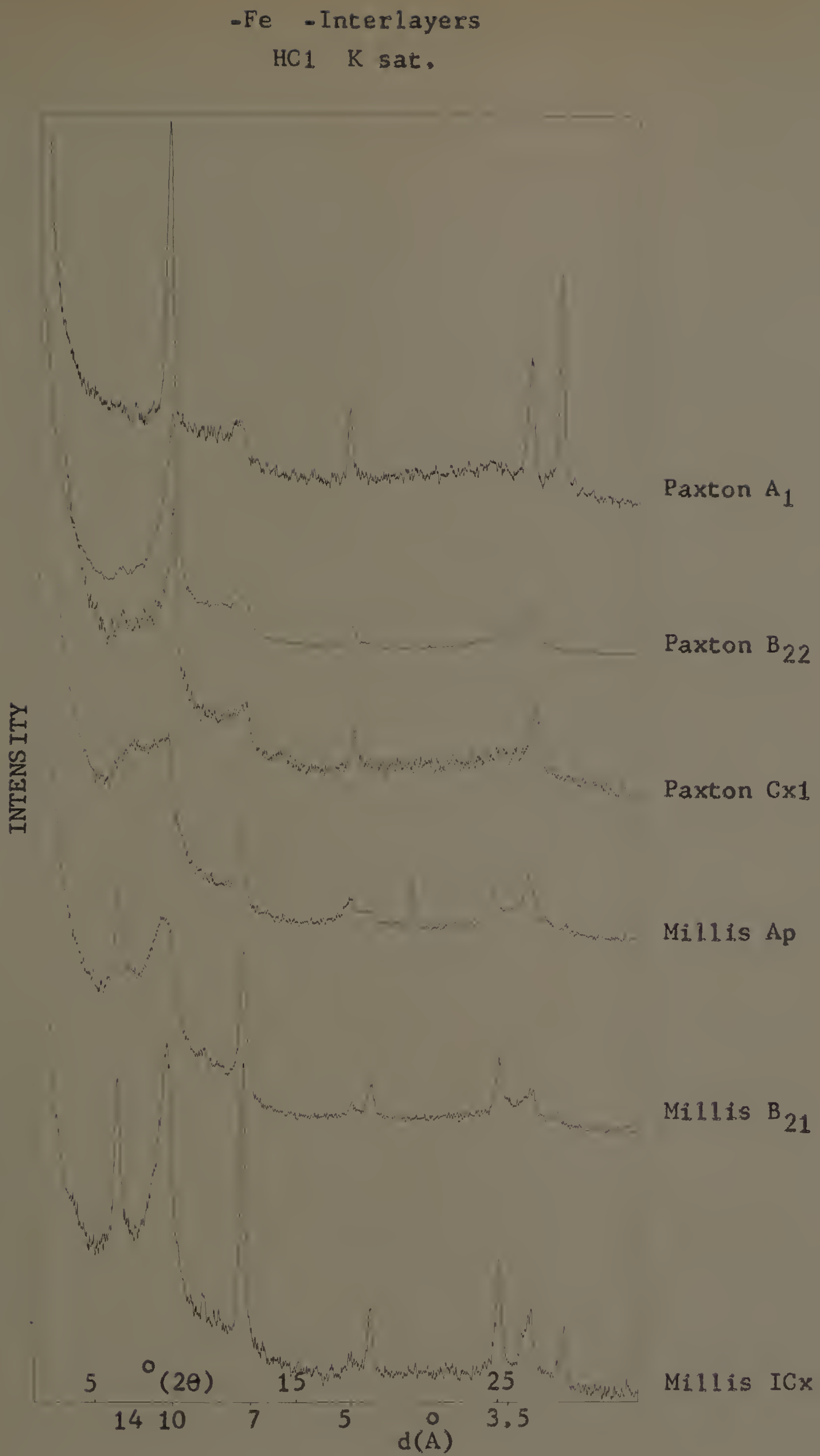

-Fe -Interlayers
HCl K sat.
INTENSITY
Paxton A_1
Paxton B_{22}
Paxton Cx1
Millis Ap
Millis B_{21}
Millis ICx
5 °(2θ) 15 25
14 10 7 5 3.5
d(Å)

Fig. 29

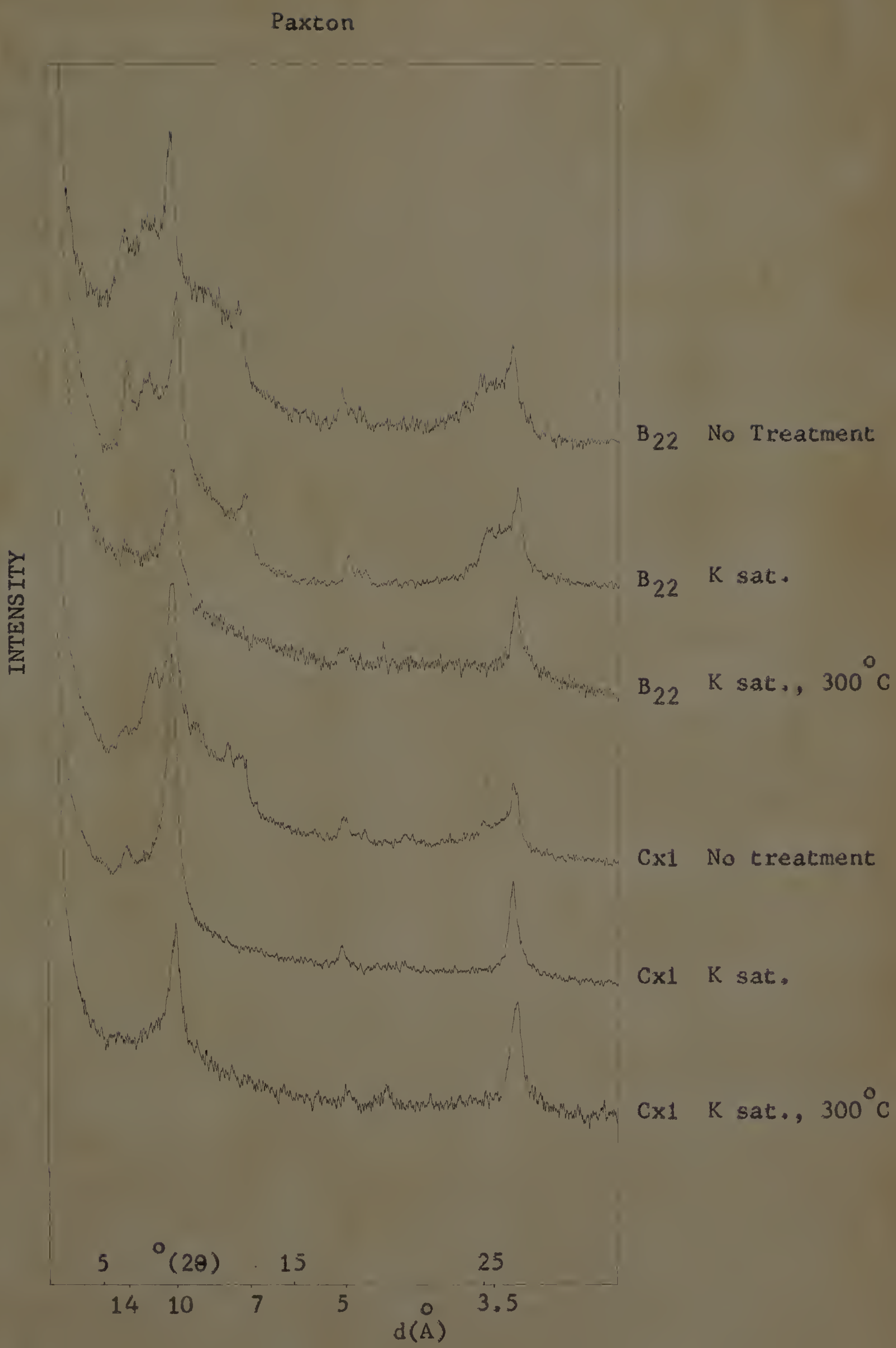

Paxton
INTENSITY
B_{22} No Treatment
B_{22} K sat.
B_{22} K sat., 300 °C
Cx1 No treatment
Cx1 K sat.
Cx1 K sat., 300 °C
5 °(2θ) 15 25
14 10 7 5 3.5
d(Å)

Fig. 30

residual 14Å peak is interpreted as chlorite and the portion of the 14Å peak that collapsed is interpreted as chloritized vermiculite (Fig. 28).

In Fig. 29 a sequence of patterns of A, B, and C horizons of both soils having an Fe removal, an interlayer removal, HCl treatment and K saturation is shown. The 14Å peak of the Paxton horizons all collapse to 10Å. In the Millis, where chlorite is present, the residual 14Å peak is sharpest in the ICx where weathering is the least intense. In Millis chloritized vermiculite is probably formed by weathering of both mica and chlorite.

In addition to the chlorite found only in Millis, another significant difference between the two soils is a 12Å peak is interpreted as a sodium saturated vermiculite with one water layer. Other possibilities include a hydro-biotite or a random interstratified vermiculite-mica. The 12Å peak seems to be a characteristic of lower till while being absent from upper till (Robert M. Newton, Department of Geology, University of Massachusetts, personal communication, 1976).

It is interesting to note that the x-ray diffraction patterns (without treatment) of the B_{22} and crack material of Paxton are very similar. This indicates that weathering environments of the B_{22} horizon and crack are nearly identical or else that material from the B_{22} has illuviated in the crack.

In Millis, the x-ray diffraction patterns of silt caps are nearly identical to the ICx horizons where the silt caps were sampled. This seems to indicate either that a significant amount of clay has not moved from horizons above the ICx or that clay that has moved has been altered.

Analyses for organic carbon, exchangeable cations, cation exchange capacity and pH are given in Table 3.

Organic Carbon -- Organic carbon decreases with depth in Paxton and Millis. Polygonal crack material has a slightly higher organic carbon value than the fragipan matrix. This correlates well with field observations of roots being restricted to polygonal cracks.

Exchangeable Cations and Cation Exchange Capacity -- Cation exchange capacity and exchangeable cations also decrease with depth for both Paxton and Millis.

An anomalous concentration of exchangeable Ca was found in the IICx horizon of Millis. No effort to investigate the high Ca concentration was made; however, the cation exchange capacity and exchangeable Ca was calculated twice from two samples of the IICx horizon taken at least five feet apart. The parent material does contain a small percentage of Triassic fragments, which may act as a source of Ca.

pH -- pH increases with depth in both profiles. This is typical of podzolic soils. It is interesting to note that the pH of B_{22} in Paxton is very close to the pH of the polygonal crack material e.g., 4.81 to 4.87.

TABLE 3 Chemical Properties of the Profiles

Horizon	Depth Sampled in inches	pH 1:1 solution	%Organic Carbon	Exchangeable Bases Ca	Exchangeable Bases Mg	Na	K	Sum Bases	Ext. Acidity	CEC	%Base Sat.
			Paxton - Northampton								
A1	2	4.64	2.50	0.150	0.013	0.042	0.015	0.220	7.840	8.06	2.73
B21	6	5.40	0.47	.0	0.005	0.002	0.003	0.010	3.990	4.00	0.25
B22	19	4.81	0.51	0.130	0.010	0.042	0.011	0.193	5.037	5.23	3.69
Cx1	36	5.18	0.04	0.850	0.038	0.052	0.010	0.950	3.550	4.50	21.11
Cx2	65	5.30	0.08	1.375	0.050	0.049	0.011	1.485	1.845	3.33	44.59
Crack	26	4.87	0.35	0.950	0.033	0.022	0.011	1.016	3.484	4.50	22.58
Crack	60	4.82	0.35	1.110	0.059	0.022	0.013	1.194	3.466	4.66	25.62
			Millis - Belchertown								
A1	2	4.95	2.69	0.500	0.012	0.129	0.013	0.654	6.676	7.33	8.92
B21	9	5.06	0.78	0.250	0.009	0.420	0.038	0.974	3.021	4.00	24.48
B22	22	5.82	0.66	0.625	0.008	0.028	0.002	0.663	3.167	3.83	17.31
ICx	36	6.15	0.51	0.250	0.003	0.030	0.001	0.284	1.546	1.83	15.52
IICx	79	6.18	0.47	5.000	0.073	0.036	0.003		1.738	2.16	

DISCUSSION

The stratigraphy of the Paxton study site in the Northampton borrow pit consists of about 10-15 feet of unsorted debris over 10-12 feet of glaciofluvial sand and gravel having deltaic bedding. At the base of the section unoxidized lower till is exposed in several places (Fig. 31).

There is some evidence that the unsorted debris is colluvium. A possible thrust fault was found at a contact between the unsorted debris and the glaciofluvial material; relative movement on the fault is to the north (Figs. 32 and 33). Several till balls were found embedded in the fault (Fig. 34). Since a northerly glacial advance is doubtful, and deposition of the unsorted debris seems to be from the south, the possibility of colluvium exists.

A solifluction type creep for the lobe seems unlikely. It is difficult to imagine that materials creeping downhill could cause a thrust fault of the magnitude of the one observed. A mass slide occurring on the order of thousands of years B.P. is postulated. Although most deposits thought to be colluvial in Massachusetts are of sandier material, a deposit of similar particle size distribution to the unsorted debris at Northampton and having an age of 6000 years B.P. has been reported at Nash Stream, New Hampshire (Pessl and Koteff, 1970).

Almost all boulders on the slope above the borrow pit have an upslope dip to them. The larger boulders have slip scars (Fig. 35) on their upslope side and piles of smaller bulldozed boulders on their downslope side (Fig. 36). This indicates some modern soil creep downslope. This phenomenon was described by Lyford and others in the Harvard School Forest on a fragipan soil (Lyford and others, 1963).

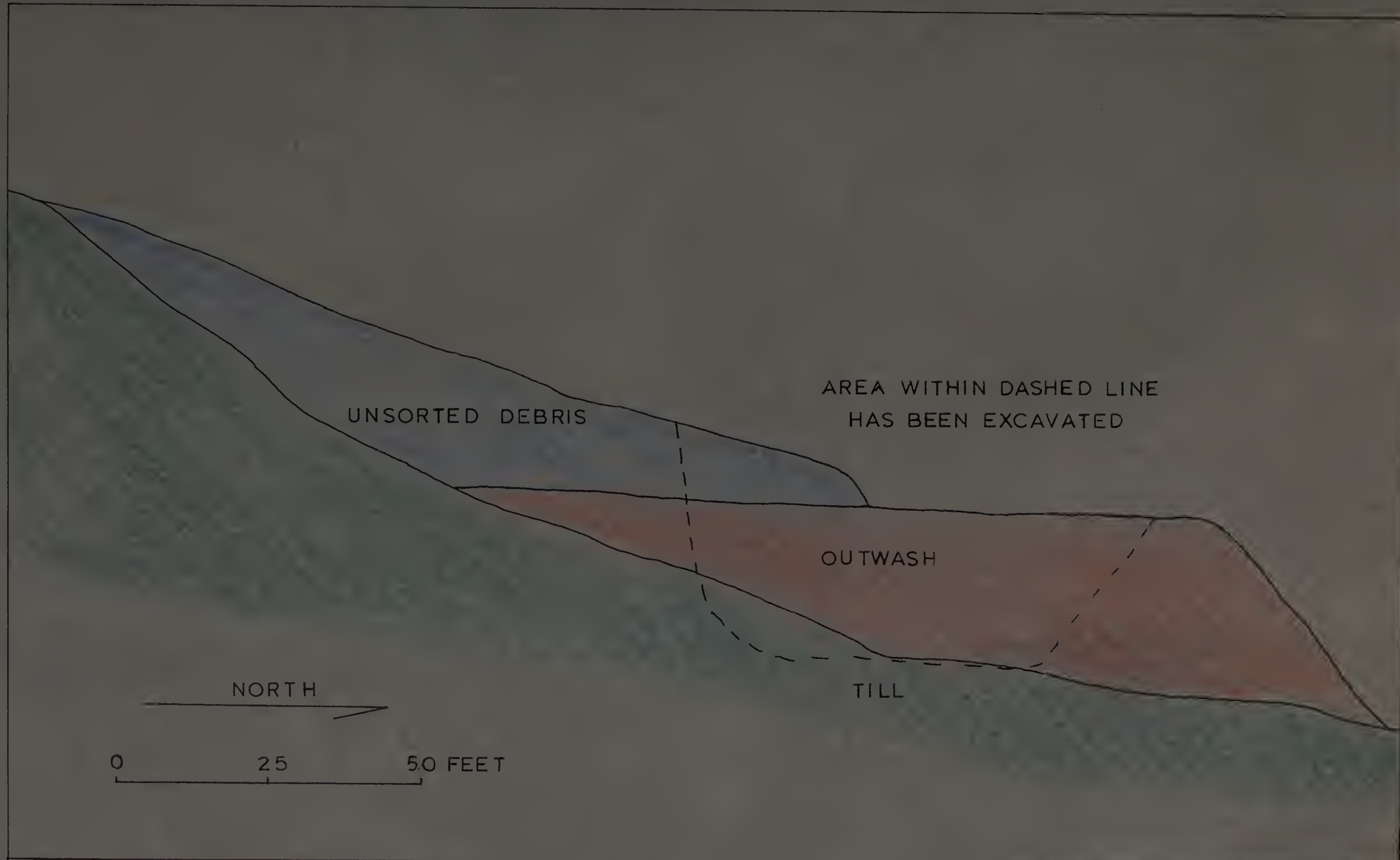


Fig. 31

STRATIGRAPHY OF THE PAXTON STUDY SITE AT NORTHAMPTON

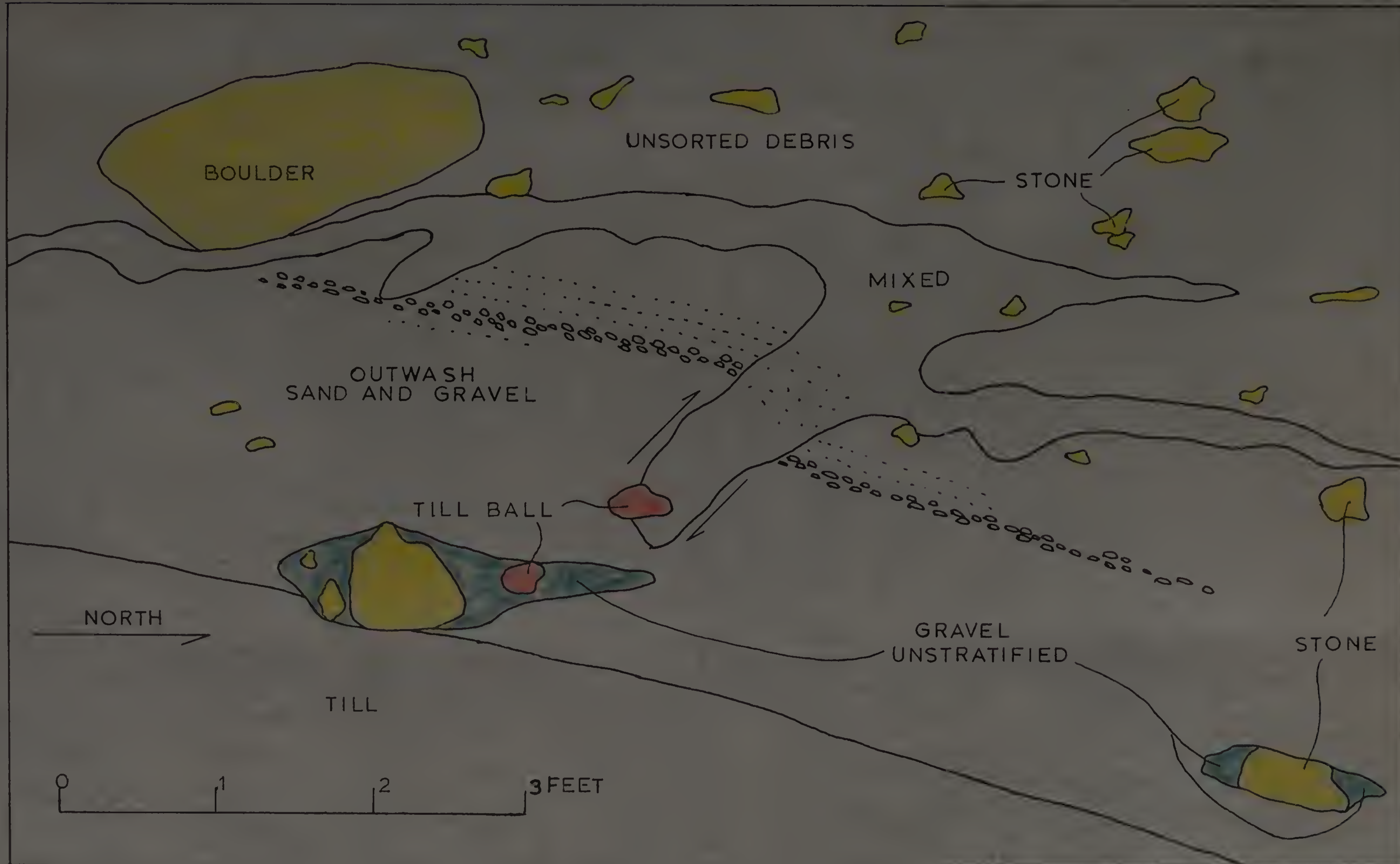


Fig. 32
DIAGRAM OF THRUST FAULT AT PAXTON STUDY SITE NORTHAMPTON

Fig. 33 Thrust Fault.
Paxton, Northampton

Fig. 34 Till balls embedded in thrust fault. Paxton, Northampton.

Fig. 35 Slip scar, clear of stones, upslope of large boulder. Paxton, Northampton.

Fig. 36 Bulldozed stones downslope of large boulder. Paxton, Northampton.

The unsorted debris is believed to have been deposited as a slurry because of a lack of grain to grain contacts as observed in thin section.

The high bulk density and compactness of the unsorted debris is thought to be due to desiccation processes and a well sorted particle size distribution. The presence of vesicles and the polygonal arrangement of near vertical cracks, when viewed in plan, implies that desiccation has occurred (Figs. 37 and 38). The entire 10 to 12 feet of unsorted debris, with the exception of the A and B horizons is hard and compact. Samples of the A and B horizons become hard and brittle when their organic matter is destroyed and they are saturated with water and allowed to desiccate at room temperature.

The properties of the material filling the cracks are very similar to the properties of the B_{22} horizon i.e., percent organic carbon, bulk density, pH, and clay mineralogy. There should be a tendency for the cracks to enlarge with time, thus degrading the compact layer and enlarging the B_{22} horizon. Ranney and others (1975) felt that material filling cracks of fragipans in Pennsylvania was from weathering and additions from above.

All cracks observed in the lower till are not desiccation cracks (Fig. 39). Many of the cracks are faults and joints caused by movement of the till after deposition by gravity or glacial tectonism (Robert M. Newton, Department of Geology, Univeristy of Massachusetts, personal communication, 1976). However, the tendency for the joints and faults to enlarge and form B horizon like material is probably the same as desiccation cracks.

The Millis study site in Belchertown is formed from bedrock controlled ground moraine. As with the Paxton Cx horizons, there are vesicles in the

Fig. 37 Near verticle crack. Roots are present only in the crack. Paxton, Northampton.

Fig. 38 Plan view of cracks forming polygons. Depth is approximately 40 inches. Paxton, Northampton.

Fig. 39 Plan view of cracks or joints. Depth is approximately 40 inches. Paxton, Spencer.

Millis Cx horizons indicating desiccation of the parent materials (Fig. 40). One of the most striking features of the Millis Cx horizon is the presence of silt caps and sand beds (Fig. 41).

A silt cap is probably formed by fines (i.e., silt and clay) moving through the soil matrix. Examination of a thin-section of a silt cap clearly demonstrated that fines have moved onto a coarse fragment, causing the sand which did not move to collapse. Also, illuviation rather than segregation of fines by ice is indicated because of the preferred orientation i.e., most silt caps are oriented toward the topographic surface. Silt caps were probably formed while till desiccated shortly after the ice retreated.

Coarse fragments act as umbrellas catching fines from above. A sand bed develops under a coarse fragment because losses of silt occur at this site, but additions of silt are blocked by the coarse fragment.

Boulten and Dent (1974) have observed silt caps forming in freshly exposed till in Iceland. Movement of fines in upper till in New England at present is probably slight. Silt caps have never been observed in A and B horizons in soils developed from upper till. However, they are always present in Cx horizons.

Flock (1960) has shown that some oriented silt and clay is present on ped faces of B horizons of Sols Bruns Acides (e.g., Teas silt loam, West Virginia). No oriented silt and clay have been observed in thin-sections of B horizons during this study.

In soils developed from lower till, evidence of movement of clay and possibly fine silt i.e., cutans is almost always present on the surfaces of platy peds in the upper part of the Cx horizon. This is probably due to the movement of ground water along ped faces. In thin-sections of the

Fig. 40 Vesicles in fragment of ICx horizon of Millis, Belchertown.

Fig. 41 Silt cap of coarse fragment from ICx horizon of Millis, Belchertown.

Cx horizon of Paxton at Northampton, evidence of clay movement is present along ped faces down to 79 inches, the greatest depth sampled. However, in lower till sampled in New Hampshire, Massachusetts and Connecticut at depths greater than 60 inches evidence of movement of clay is rare (Robert M. Newton, Department of Geology, University of Massachusetts, personal communication, 1976).

Platy structure is almost always present in Paxton soils and is sometimes present in Millis soils (Fig. 42). The genesis of this structure is complex. It is felt that the platy structure in the upper Cx horizon is caused by desiccation and freeze-thaw process. Platy structure has been produced from a slurry of unoxidized till taken from the Northampton study site and allowed to freeze-thaw and desiccate over the winter months (Peter Fletcher, Department of Plant and Soil Science, University of Massachusetts, unpublished data, 1976). Similar results have also been produced by Fitzpatrick (1956) in a till from Norway.

Deep platy structure is thought to be inherited from the glacial till parent material. In a deep borrow pit at Thomaston Dam, Connecticut plates were gently folded at a depth of approximately 20 feet. Above the folded plates were plates parallel to the soil surface. A depth of 20 feet is below frost penetration, and processes causing folding at this depth are probably related to events of the Pleistocene. Boulton and Dent (1974) also relate platy structure to till.

Most water movement through fragipans is probably by way of cracks, joints and faults. Although the matrices of the fragipans have low hydraulic conductivities water seeping from cracks, joints, and faults have been observed. Platy structure must also play a major role in conducting water. Iron stains of the surface of plates in Northampton seems to indicate that water moves along these surfaces (Fig. 43). When the spaces between plates are waterlogged Fe^{+2} would move with the water, and as desiccation took place Fe^{+3} would be deposited on plate surfaces. This accounts for the hematite-like stains on plate surfaces in the Cx horizon of Paxton at Northampton.

Fig. 42 Platy structure (fissility) in Paxton, Northampton.

Fig. 43 Platy structure. Stains on plate surfaces are common. Paxton, Northampton.

CONCLUSIONS

Paxton and Millis soils fit the definition of fragipan soils as given in Soil Taxonomy (Soil Survey Staff, 1970). The Cx horizons of both soils are low in organic matter, have a high bulk density relative to the horizons above, and dry fragments of the Cx slake in water (Figs. 44 and 45).

The hardness and compactness of Millis and Paxton fragipan horizons are believed to be inherited from the till parent material. The hardness and compactness are thought be be due to the well graded particle size distribution, lack of organic matter and desiccation. The presence of desiccation processes is supported by the presence of vesicles. Vesicles were produced in the laboratory by allowing saturated samples of till to desiccate. If the till has the correct particle size distribution, e.g., greater than 8 percent clay and less than 70 percent sand, desiccation cracks should develop. Material filling the cracks are probably additions both from above and from weathering of the adjacent soil matrix. There should be a tendency for the cracks to expand and enlarge the B horizon with time. Some soils in the southern United States and Europe have a morphology similar to fragipan soils in New England but are friable and have extremely large filled cracks. This seems to indicate that these soils have degraded pans (Lindo J. Bartelli, Principal Soil Correlator, Soil Conservation Service, Washington, D.C., personal communication, 1976). The concept of fragipans degrading with time is important and should be studied more fully. Other soils such as Buxton, formed from glaciolacustrine deposits in New England, also have desiccation cracks (Fig. 46, Hill and Sawhney, 1969). Similar pedogenic processes probably occur in these soils.

Fig. 44 Dry fragments of Millis and Paxton Cx horizons and unoxidized lower till from Belchertown and Northampton, respectively.

Fig. 45 Fragments slake when placed in water.

Fig. 46 Near verticle crack in Buxton (glaciolacustrine deposits) from eastern Massachusetts.

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APPENDIX

APPENDIX A

PAXTON SERIES

The Paxton series is a member of the coarse-loamy, mixed, mesic family of Typic Fragiochrepts. These soils have very dark grayish brown fine sandy loam surface horizons and yellowish brown and light olive brown fine sandy loam B horizons underlain by a fragipan at depths of 15 to 36 inches.

Typifying Pedon: Paxton fine sandy loam-hayfield (Colors are for moist soil)

Ap -- 0-8" -- Very dark grayish brown (10YR 3/2) fine sandy loam; weak, fine, granular structure; friable; many roots; 5 percent gravel; medium acid; abrupt smooth boundary; (5 to 9 inches thick.)

B21 -- 8-11" -- Yellowish brown (10YR 5/6) fine sandy loam; weak, medium, granular structure; friable; many roots; 5 percent gravel; slightly acid; abrupt wavy boundary; (2 to 6 inches thick.)

B22 -- 11-22" -- Light olive brown (2.5Y 5/4) fine sandy loam; weak, thick, platy structure; firm; common roots; 15 percent gravel; medium acid; clear wavy boundary; (8 to 11 inches thick.)

CX -- 22-41" -- Grayish brown (2.5Y 5/2) crushed mass is olive (5Y 5/3) fine sandy loam; moderate, thick, platy structure; very firm; no roots; 15 percent gravel; medium acid.

Type Location: Strafford County, New Hanpshire, town of Strafford. Caverly Hill about 2 miles southeast of Bow Lake Village on Leighton Farm. Site located in hayfield about 150 feet south of farmhouse. USGS Mt. Pawtuckaway 15' quadrangle; 43°13'50"N and 71°07'10"W. State Plane Coordinates; Zone 0, E/W 646200, N/S 267000.

Range in Characteristics: The depth to the fragipan ranges from 15 to 36 inches. Coarse fragments in both the solum and fragipan range from

5 to 30 percent. The silt content throughout the solum and C horizons ranges up to 45 percent. Reaction of the solum and underlying till ranges from strongly to slightly acid. In undisturbed pedons, A1 horizon moist colors are of 10YR hue with values of 2 or 3 and chromas of 1 or 2. Ap horizon colors are of hue 10YR with values of 3 or 4 and chromas of 2 to 4. Textures of A horizons are dominantly fine sandy loam or loam but range to sandy loam or gravelly analogues. Structure is dominantly weak, fine or medium granular. B21 horizon colors are dominantly of hue 10YR with value of 5 and chromas of 6 and 8 and of hue 7.5YR with value of 5 and chromas of 6 and 8. B22 horizon colors are of hue 2.5Y with value of 5 and chromas of 3 and 4 and of hue 10YR with value of 5 and chromas of 4 and 6. Textures in the B2 horizons are dominantly fine sandy loam or loam but range to sandy loam or gravelly analogues. The structure of B2 horizons is dominantly weak, fine or medium granular but ranges to weak, thin to thick, platy in the lower B2. An A 2 horizon is present in some pedons. A few mottles occur immediately above the fragipan or within the fragipan in some pedons. C horizon colors are of hue 2.5Y with values of 4 to 6 and chromas of 2 and 4 and of hue 5Y with values of 4 to 6 and chromas of 2 and 3. Texture of C horizons is dominantly fine sandy loam or loam or gravelly analogues but ranges to sandy loam or gravelly sandy loam. Structure of C or CX horizons is dominantly weak or moderate, medium or thick platy but ranges to thin platy or is massive. Consistence of CX horizons is firm or very firm with brittleness characteristics of fragipans.

Competing Series and Their Differentiae: The Bernardston, Broadbrook and Newport are members of the same family. Bernardston soils have a higher silt content in the solum and fragipan. Broadbrook soils have a silty mantle overlying a loamy fragipan. Newport soils have B21 horizons with color values less than 5, moist, and hues less red than 10YR. Closely related soils are the Charlton, Essex, Marlow and Woodbridge. Charlton soils lack a fragipan. Essex soils have coarse texture. Marlow has at least 1.2 percent organic carbon in the upper 4 inches of the spodic horizon and is colder. Woodbridge soils have mottles in the lower spodic horizon.

Setting: The Paxton soils occupy the nearly level to sloping positions on drumlins and sloping areas of glaciated uplands. Slopes generally range from 0 to 25 percent. The regolith is compact acid stony glacial till of Wisconsin age that is derived mainly from mica schist and granite. The climate is humid and cool temerate. Mean annual precipitation ranges from 37 to 49 inches and the frost free season from 115 to 180 days.

Principal Associated Soils: The moderately well drained Woodbridge, poorly drained Ridgebury and very poorly drained Whitman are members of the same drainage sequence. Common associates are the Charlton, Sutton and Leicester, but these soils all lack a fragipan. Hollis soils have bedrock within depths of 20 inches but also occur in close association with the Paxton.

Drainage and Permeability: Well-drained. Runoff is medium or rapid depending on slope. Permeability is moderate above the fragipan and slow in the fragipan. Water moves laterally along the top of the fragipan.

Use and Vegetation: Areas cleared of stones are used mainly for hay and pasture. Apple orchards and potatoes are also common crops. In wooded areas, the principal species are red oak, sugar maple, hemlock and white pine.

Distribution and Extent: New England and eastern New York. The series is of large extent, with an area of about 600,000 acres.

Series Established: Worcester County, Massachusetts, 1922.

Remarks: Formerly classified as a Brown Podzolic in the 1938 classification system.

Additional Data: The Paxton benchmark soils report. Bulletin 662, December 1963, issued by Connecticut Agricultural Experiment Station, New Haven, Connecticut.

National Cooperative Soil Survey

U. S. A.

Tentative Series
JAF-SJZ 1/3/69

APPENDIX B

MILLIS SERIES

The Millis series is a member of a coarse-loamy over sandy or sandy-skeletal, mixed, mesic family of Typic Fragiocrepts. The Millis soils have an 18 to 30 inch thick fine sandy loam mantle that is underlain by a gravelly loamy sand fragipan in sandy glacial till.

Typifying Pedon: Millis very stony fine sandy loam - forested, mainly oak and white pine. (All colors for moist soil.)

01 -- 2-0" -- Leaf litter of pine needles and oak leaves.

A1 -- 0-1" -- Black (10YR 2/1) fine sandy loam; moderate very fine and fine crumb; very friable; medium roots abundant; 5 to 15 percent coarse fragments; abrupt irregular boundary. (0 to 3 inches thick.)

B21h -- 1-2" -- Brown to dark brown (7.5YR 4/2) fine sandy loam; weak very fine and fine crumbs; very friable; medium roots abundant; 5 to 15 percent coarse fragments; abrupt irregular boundary. (0 to 2 inches thick.)

B22 -- 2-15" -- Yellowish-brown (10YR 5/8) fine sandy loam; massive with weak fine crumbs along roots; very friable; medium roots abundant; 5 to 15 percent coarse fragments; clear wavy boundary. (5 to 10 inches thick.)

B23 -- 15-22" -- Yellowish-brown (20YR 5/6) fine sandy loam; massive with weak fine crumbs along roots; very friable; medium roots common; 10 to 25 percent coarse fragments; abrupt wavy boundary. (5 to 15 inches thick.)
Sample #11

IIC1 -- 22-28" -- Pale olive (5Y 6/3) gravelly loamy sand; massive breaking to single grain; friable; few roots; 35 to 45 percent coarse fragments; abrupt wavy boundary. (5 to 10 inches thick.)

IIC2x -- 28-42"+ -- Light olive gray (5Y 6/2) gravelly loamy sand; massive, breaks out in angular blocky clods that are brittle; firm; few roots in upper part, none in lower part; 35 to 45 percent coarse fragments.

<u>Location</u>: Middlesex County, Massachusetts, Town of Bedford. Located in

a road out at Stage Coach Estates, Wagon Wheel Drive.

Range in Characteristics: Solum thickness is 18 to 30 inches and corresponds closely to the depth to the underlying coarse textured till. The fragipan generally is at a depth of 25 to 35 inches from the surface. Content of angular coarse fragments of pebbles, cobblestones and stones ranges from 5 to 20 percent in the solum and 10 to more than 50 percent in the IIC horizons. Most Millis soils have a very stony or extremely stony surface except where stones have been removed. Clay content is less than 18 percent. Reaction ranges from extremely acid through strongly acid where not limed. There is less than 2 percent organic matter within 4 inches below the Ap. Extractable carbon, plus iron, plus aluminum generally exceeds 1 percent, and its ratio to percent clay is more than 0.15. Mean annual soil temperature at 20 inches ranges from 47°F. to 53°F. The A1 horizon has colors with a hue of 10YR, a value of 2 or 3, and a chroma of 1 or 2. The Ap horizon has similar colors, except the values and chromas are higher. The A horizons have a fine sandy loam, sandy loam, or very fine sandy loam texture; a weak or moderate crumb or granular structure; and a very friable consistence. In unplowed areas there may be a thin, discontinuous, grayish A2 horizon. Color of the B horizons becomes paler with depth. The B21h has colors with a hue of 7.5YR, a value of 3 or 4 and a chroma of 2 or 3. The B22 horizon has colors with a hue of 10YR or 7.5YR, a value of 4 or 5, and chromas of 4 through 8. The B23 horizon has colors with a hue of 2.5Y or 10YR, values of 4 through 7, and chromas of 4 through 6. The texture of the B horizons is dominantly a fine sandy loam (with less than 50 percent fine sand or coarser) but includes loam and very fine sandy loam (with more than 15 percent coarser than very fine sand).

They have a weak crumb or granular structure or are massive and have a very friable or friable consistence. The IIC1 horizon has colors with a hue of 2.5Y or 5Y, values of 5 through 7, and a chroma of 2 or 3. It has a gravelly loamy sand, gravelly loamy fine, gravelly loamy coarse sand or very gravelly analogs of these textures. The IIC1 is massive or has weak thin or medium platy structure. Consistence is very friable, friable or firm. The IIC2x has colors with 5Y or 2.5Y hue, a value of 5 to 7 and a chroma of 2 or 3. Texture is commonly gravelly loamy sand but includes gravelly loamy fine sand, gravelly loamy sand, gravelly loamy coarse sand and very gravelly analogs of these textures. The horizon is massive or has weak, thin or medium plates. Consistence is firm to extremely firm. Color notations are for moist soil; dry colors are 1 to 3 units higher in value.

Competing Series and Their Differentiae: These are the Canton, Paxton, Charlton, Essex, Broadbrook, Poquonock, Bernardston and Hollis series. Canton is very similar but does not have a fragipan. Paxton and Charlton have finer textures throughout the control section and Charlton does not have a fragipan. Essex has dominantly loamy sand B horizons. Broadbrook and Bernardston have a finer textured solum; in addition, Broadbrook has a sandy loam or loam fragipan and Bernardston has a darker color and a silt loam or loam fragipan. Poquocock has a loamy sand or sand solum and a loam or fine sandy loam fragipan. Hollis has a coarse loamy solum but is underlain by bedrock within 20 inches of the surface.

Setting: Millis soils occur on glacial till upland plains, hills and ridges. Slope gradients range from 0 to more than 35 percent but are dominantly 3 to 25 percent. The regolith consists of a fine sandy loam mantle over sandy glacial till of Wisconsin age derived mainly from granite and gneiss. In some places the till may contain considerable fine grained sandstone rock fragments. The till is stony and is very strongly or strongly acid. The climate is humid temperate; the mean annual temperature is 46°F. to 50°F., and the mean annual precipitation is 42 to 46 inches.

Principal Associated Soils: The Millis soils are associated with the Hollis, Paxton, Woodbridge, Ridgebury and Whitman soils of similar lithology. They are also closely associated with the similar Canton soils. They are less extensively associated with Hinckley, Merrimac, Windsor, Sudbury and Deerfield soils developed in glaciofluvium and Shapleigh, Essex, Gloucester, Acton, Scituate, Norwell and Brockton soils developed in sandy glacial till.

Drainage and Permeability: Well drained, Runoff is medium. Internal drainage is medium. Permeability is moderately rapid or rapid in the solum and slow in the fragipan.

Use and Vegetation: Mostly forested or idle. Some areas have been cleared of surface stone and are used for crops and pasture. Native vegetation is forest composed of white pine, red, white and black oaks, hickory, red maple, sugar maple, gray birch, beech, hemlock and white ash.

Distribution and Extent: Connecticut, Massachusetts, and probably New Hampshire, Maine and New York. The series is extensive.

Series Proposed: Norfolk County, Massachusetts, October 1966. Named for the Town of Millis in Norfolk County, Massachusetts.

Remarks: The Millis soils would be classed as Brown Podzolic soils in the 1938 classification system. They were formerly mapped as Essex fine sandy loam and Paxton fine sandy loam in Massachusetts.

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Series Established: Worcester County, Massachusetts, 1922.

Remarks: Formerly classified as a Brown Podzolic in the 1938 classification system.

Additional Data: The Paxton benchmark soils report. Bulletin 662, December 1963, issued by Connecticut Agricultural Experiment Station, New Haven, Connecticut.

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